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GEOLOGY OF GLAUCONITE[1]

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ABSTRACT

Throughout the sediments in Monterey Bay, an area of more than 250 square miles, there is conclusive evidence that biotite alters to glauconite, the genesis of which has been in question for more than a century. By analogy with what is known about sedimentation in the bay, a set of facts is presented which explains the occurrence of glauconite throughout the present ocean basins and the sedimentary column. The facts are of practical value. For instance, that biotite-rich sands occurring near shore are only facies of glauconitic muds off shore is useful, not only in subsurface work but in field mapping and correlations.

FOREWORD

Glauconite is a green, blue, or brown, hydrous silicate of potassium, magnesium, aluminium, and ferrous and ferric iron. A mineral first defined more than a century ago,[3] it has been described many times since: from Recent marine sediments; from all parts of the geologic column containing marine sedimentary rocks; and from some non-marine rocks. The last occurrence, however, is uncommon.

[1] Read before the Pacific Section of the Association, at Los Angeles, November 8, 1934. Manuscript received, August 15, 1935.

[2] Geologist, Barnsdall Oil Company, Box 1060. To Eliot Blackwelder the writer is indebted for his generous coöperation while the work was in progress. Through the kindness of Walter K. Fisher facilities of the Hopkins Marine Station at Pacific Grove, California, were available. Although C. B. Van Niel presented for consideration various ideas on the chemistry involved in biotite-glauconite transition, he is in no way responsible for the statements contained in that discussion. Many friends, particularly Ralph D. Reed, A. C. Waters, R. M. Kleinpell, Hollis Hedberg, and N. L. Taliaferro, contributed information on the problem's various phases. The Geological Society of America contributed funds supporting part of the research.

[3] Ch. Keferstein, *Deutschland, Geogn. Geol. Dargestellt*, Bd. 5, Heft III (1828), p. 510.

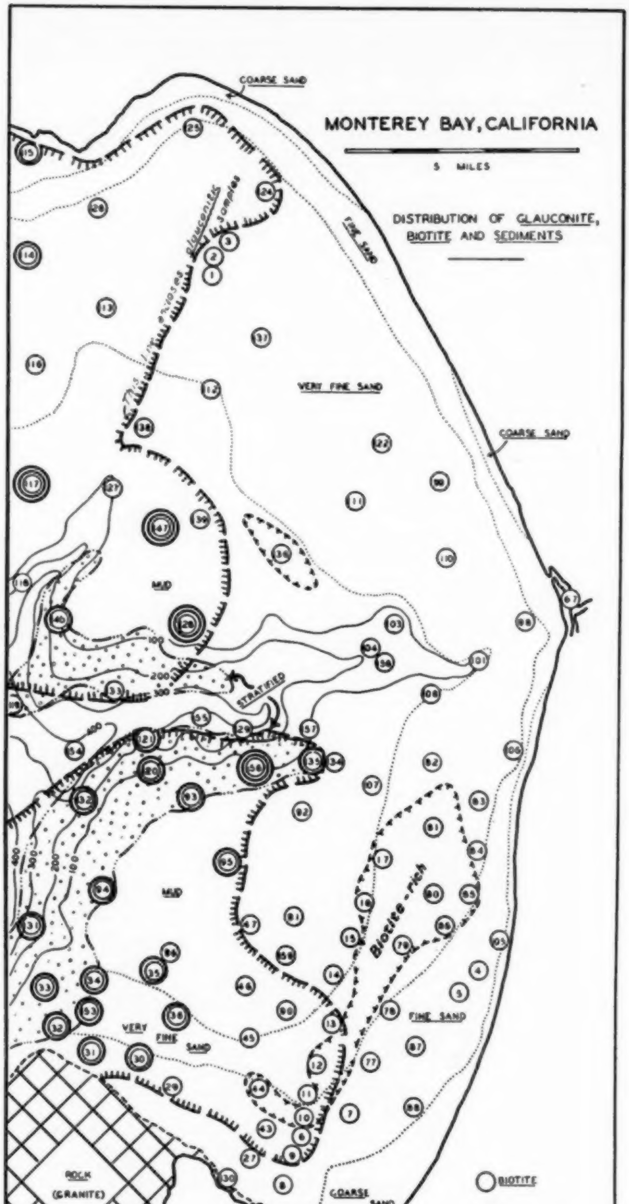
MONTEREY BAY, CALIFORNIA
5 MILES
DISTRIBUTION OF GLAUCONITE, BIOTITE AND SEDIMENTS
COARSE SAND
FINE SAND
VERY FINE SAND
MUD
STRATIFIED
Biotite-rich
ROCK (GRANITE)
ROCK
MONTEREY
PENINSULA
BIOTITE
GLAUCONITE

FIG. 1

From the beginning, the origin of glauconite has been obscure. A theory most commonly used to account for its genesis is one proposed by the *Challenger* Expedition[4] in 1891. Its authors did not consider their ideas on its mode of origin as final; nevertheless they presented a most clear and usable set of facts. Although the hypothesis has since been used practically in its entirety by some writers, there are others who have modified it or even ventured different theories.

Dredging in Monterey Bay, California, over a period of years, enabled the writer to gather a group of facts showing how glauconite is forming there now.

1. The mineral is simply a product of the alteration of biotite.
2. On an areal map of the sediments, those containing glauconite appear as off-shore equivalents of those containing biotite, but neither mineral is limited to a single lithologic facies.
3. The alteration of biotite involves: oxidation of part of its iron; retention of potash; hydration; partial loss of aluminium; changes in structure, such as swelling and cracking; and lowering of specific gravity.
4. Alteration to glauconite is apparently controlled by the length of time biotite is present in the persistently and definitely alkaline solution, sea water.
5. Some glauconite in Monterey Bay has been in process of forming since the last diastrophic movement in the region; that is, probably since Pleistocene time.
6. Where glauconite forms in the bay, deposition of marine sediments is slow.

Several years ago K. Hummel[5] observed glauconite forming in a Jurassic biotite-tuff. Although he has since received much criticism for his point of view, the present study of sediments now accumulating completely supports his idea that biotite is the progenitor of glauconite.

FIG. 1. *Distribution of glauconite, biotite, and sediments.*—Map of bottom deposits of Monterey Bay, California, showing distribution of glauconite and biotite. Sample numbers in circles.

Heavy dashed line encloses every sample containing glauconite and delimits occurrences of that mineral in sediments. Samples wherein glauconite dominates over biotite: double circles; all these contain small amounts of biotite. Samples wherein biotite is dominant over glauconite: single circles. Sediments especially rich in biotite: T-shaped lines. Stations with triple circles: spongy glauconite especially well developed.

Contours at each 100 fathoms outline central east-west channel bisecting bay.

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[4] John Murray and A. F. Renard, *Rept. Challenger Expedition, Deep Sea Deposits* (1891), p. 385.

[5] K. Hummel, "Die Oxford-Tuffte der Insel Buru und Ihre Fauna," *Palaeontographica*, Suppl. IV, Abt. III, Abs. 4 (1923), pp. 122 and 123.

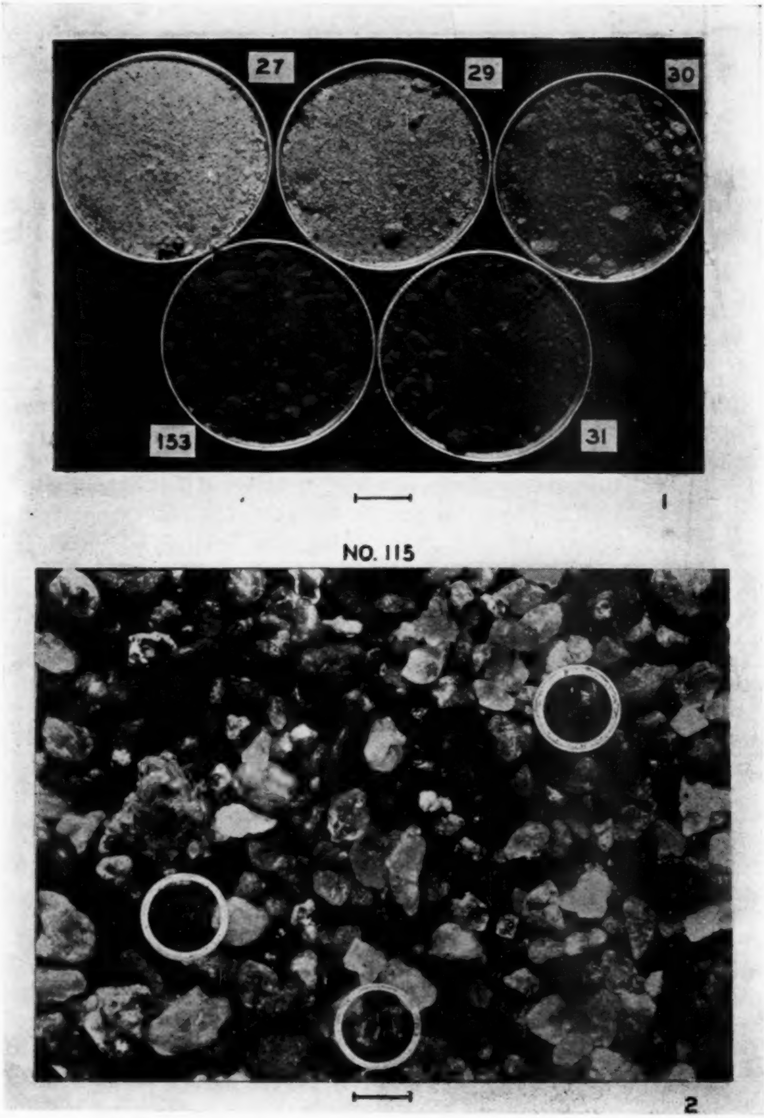

FIG. 2, 1. *Lithologic facies.*—Sediments comprising samples 27, 29, 30, 31, and 153 from south end of bay. Depths: No. 27, 25 fathoms; No. 29, 41 fathoms; No. 30, 55 fathoms; No. 31, 59 fathoms; No. 153, 57 fathoms. They illustrate color change accompanying increase in glauconite and silt. White arkose, No. 27, contains brown biotite as the only dark mineral. End sample, No. 153, is dark green due to glauconite; it has practically no biotite. Line represents 1 centimeter.

2. *Coarse sand.*—Fairly coarse sand in north end of bay, sample 115, contains large grains of glauconite enclosed by circles on left. Upper right circle encloses biotite. Material has received no washing other than that while on sea floor at 5 fathoms. Line represents 1 millimeter.

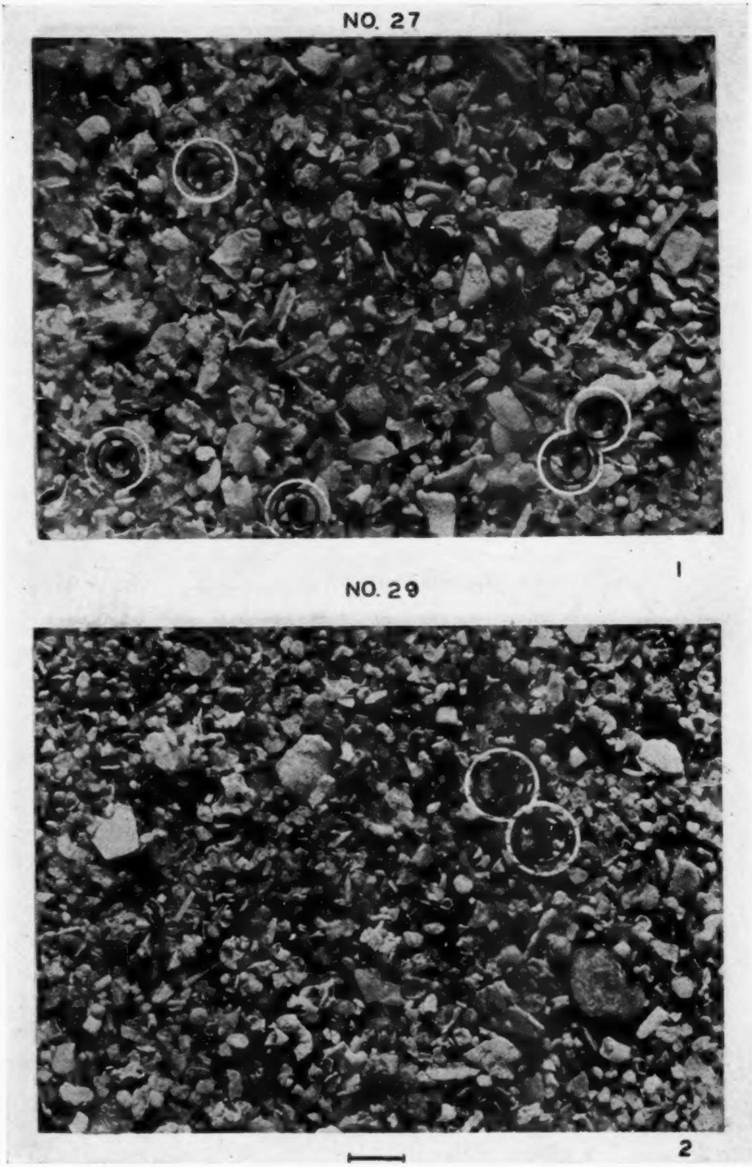

FIG. 3. *Fine shell sands.*—Naturally clean arkose with shell debris, sample No. 27; depth 25 fathoms. Flakes of brown biotite indicated. Grains unaltered and clean, with no glauconite present.

2. Sample No. 29, from a greater depth (41 fathoms) than No. 27, is finer-grained but also arkose with shell debris. Small amount of silt (not over 5 per cent), small flakes of brown and green biotite, and rare glauconite.

Line represents 1 millimeter, applying to both photos.

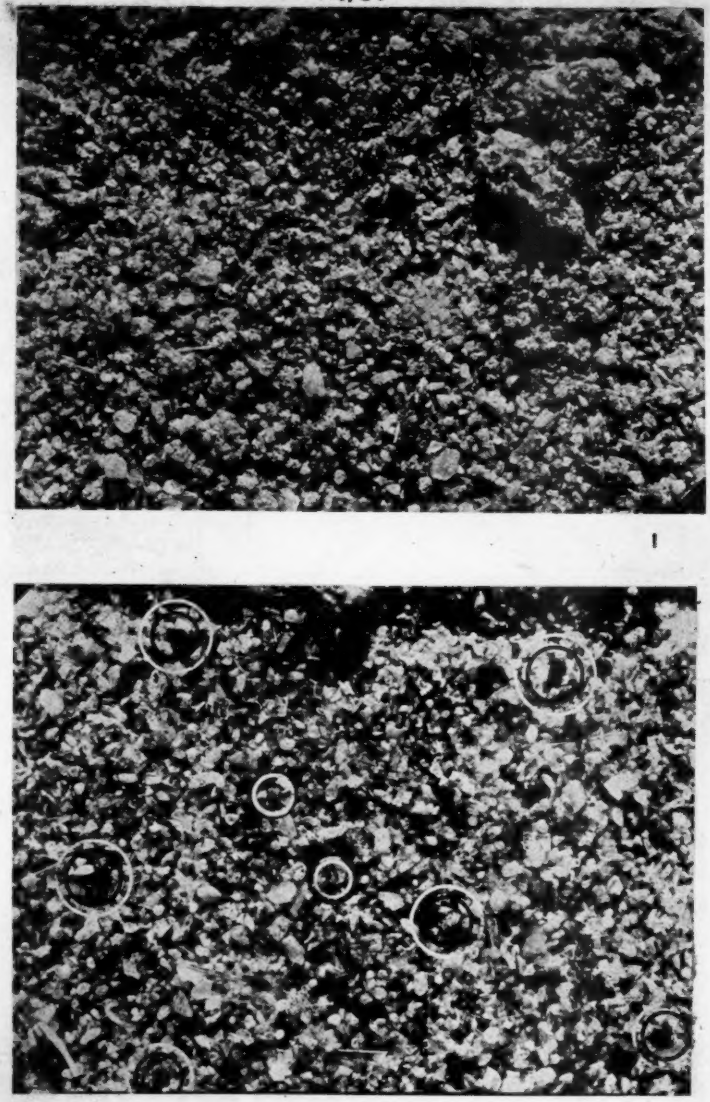

FIG. 4. *Fine silty sand.*—Although sample No. 30 contains some silt (5–10 per cent), it consists predominantly of fine arkose. Photo 1 shows the sediment as it occurs. When washed to plus 120-mesh screen, as in photo 2, biotite is visible (circles in lower and upper right, center and upper left), as well as various transition stages of biotite to glauconite (circles in lower left and lower center). Firm glauconite in upper center circle. Depth of sample, 55 fathoms. Line represents 1 millimeter.

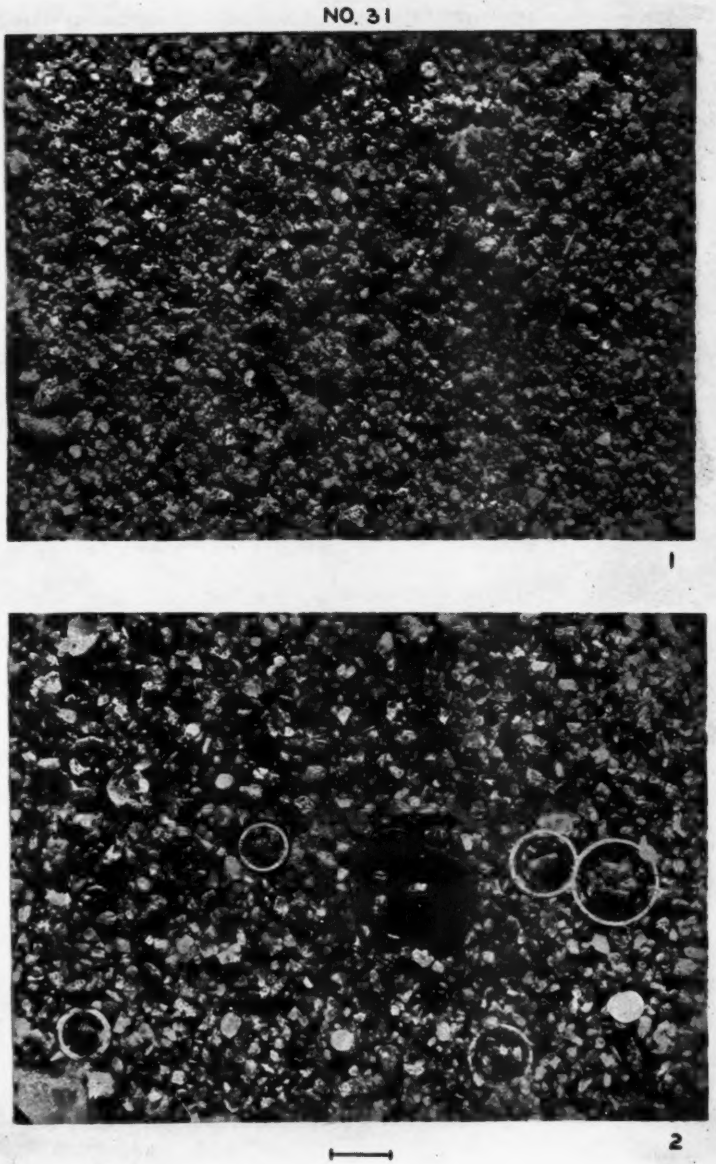

FIG. 5. *Very silty fine sand.*—Silt content of sample No. 31 as it occurs (photo 1) is 10–20 per cent. Material washed to plus 120-mesh (photo 2) shows many transition stages (lower left and center circles), as well as final glauconite stages (all circles right of center). Biotite rare, large single flake in center is dark green. Such a large flake exceptional at this depth (59 fathoms). Line represents 1 millimeter.

NO. 153

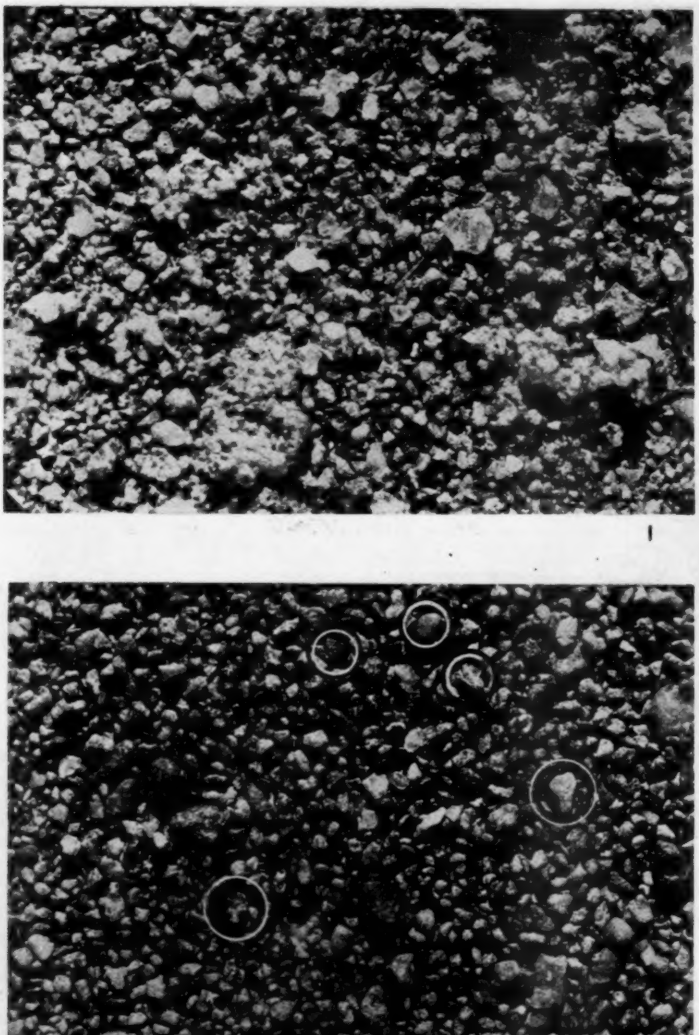

FIG. 6. *Very fine glauconite sand.*—Small amount of silt in sample No. 153 (photo 1), but material washed to plus 120-mesh (photo 2) is nearly pure concentrate of firm glauconite. Unaltered biotite rare; altered common. Upper and lower right circles: grains showing reticulate structure; lower left, upper left, and center right circles: transition stages.

Glauconite of photo 2 was freed of impurities to use in chemical analysis No. 2 in Table 1.

Material from depth of 57 fathoms. Line represents 1 millimeter.

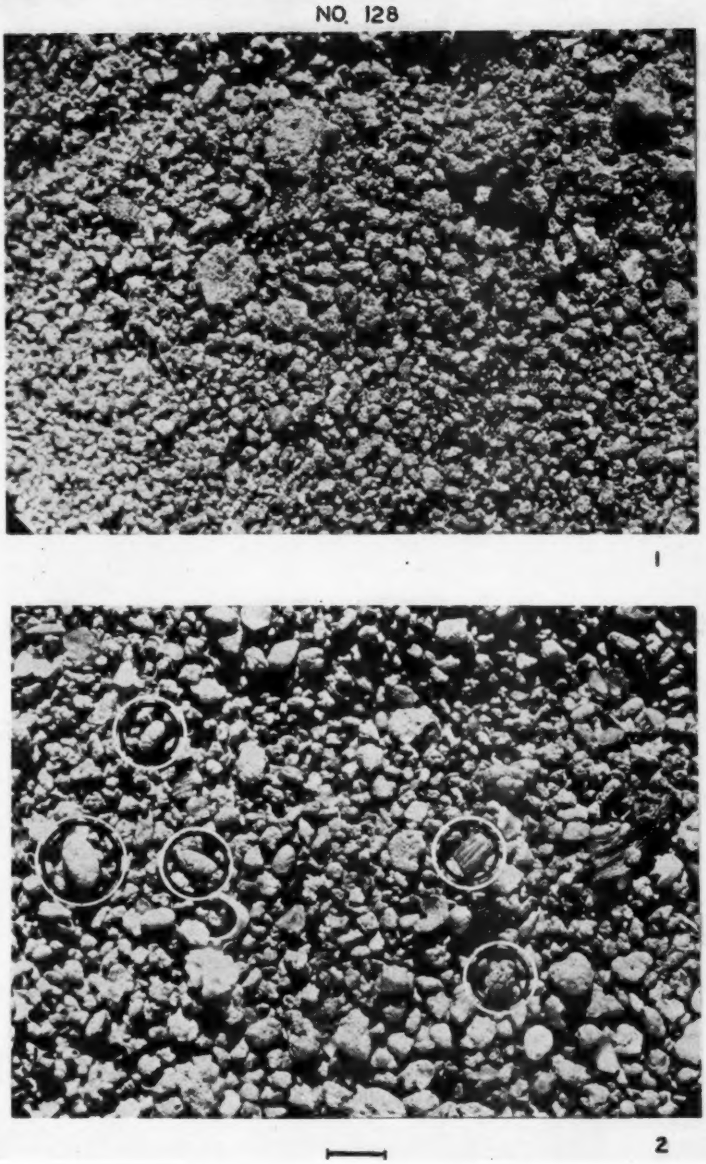

FIG. 7. *Glauconitic mud.*—With silt and clay of sample No. 128 (60 fathoms) washed away, glauconite concentrate remains. Type is porous or spongy and lighter green than that found in No. 153. Much mud in No. 128 has passed through worms' digestive tracts. As a result, many irregular, spongy grains of glauconite have been formed into coprolites (all circles except upper right). Especially good intermediate biotite–glauconite: upper right circle.

Line represents 1 millimeter.

AREAL RELATIONS OF BIOTITE AND GLAUCONITE AND THE SEDIMENTS CONTAINING THEM

LITHOLOGIC FACIES

The Recent sediments of Monterey Bay vary in color and mechanical composition, depending on change in depth and distance from shore. Sketched briefly, the sands are uniformly free of silt and well sorted near shore, especially in coarse sand areas. Distribution of coarse sand and other textural types of sediments, as well, are shown in Figure 1. In general, coarse sand does not occur below 5 fathoms, but near the southeast corner of the bay it reaches depths as great as 25 fathoms. All grains are clean and sparkling, and silt is attached to few of them. Figure 2, 2 shows sample No. 115, an example of material classified as coarse sand.

Average grain size of the sand decreases rapidly out to a mile from shore and silt there begins to make up a small percentage of the sediment. Everywhere at this distance the deposit, generally fine or very fine sand, becomes gray or greenish gray, although coarser sediments allied to the fine sand, and lying closer to shore, vary from white to buff. Fine and very fine sand areas lie approximately between 5 and 40 fathoms. Figures 3 to 6 show these materials. Figure 2, 1 shows a series of sediments located near the southern end of the bay, emphasizing the various lithologic facies containing biotite and glauconite.

At approximately 40 fathoms, sediments are dominantly silt and clay. This is designated "Mud" on the map. It is sufficiently compact and impervious practically to eliminate aeration from overlying water. Organic matter accumulating there decomposes largely under anaerobic conditions. Streaks of hydrotroilite, a black hydrous sulphide of iron, are numerous. The factors controlling the anaerobic, or reducing, environment have been presented elsewhere.[6] Samples from mud areas are generally gray or greenish gray. Figure 7 shows a typical example of material from station No. 128 in the northern part of the bay.

Sediments are being deposited on a shelf sloping gently to the 70-fathom line, whence it drops off abruptly. On its outer, or western, edge is an area of sediments showing definite evidence of stratification, indicated on the map as "Stratified." A sample taken from the area is shown in Figure 8. The texture of the top portion throughout the area varies from sand to gravel. The mud lying at the bottom of each core,

[6] E. Wayne Galliher, "The Sulfur Cycle in Sediments," *Jour. Sed. Petrol.*, Vol. 3 (1933), pp. 51–63.

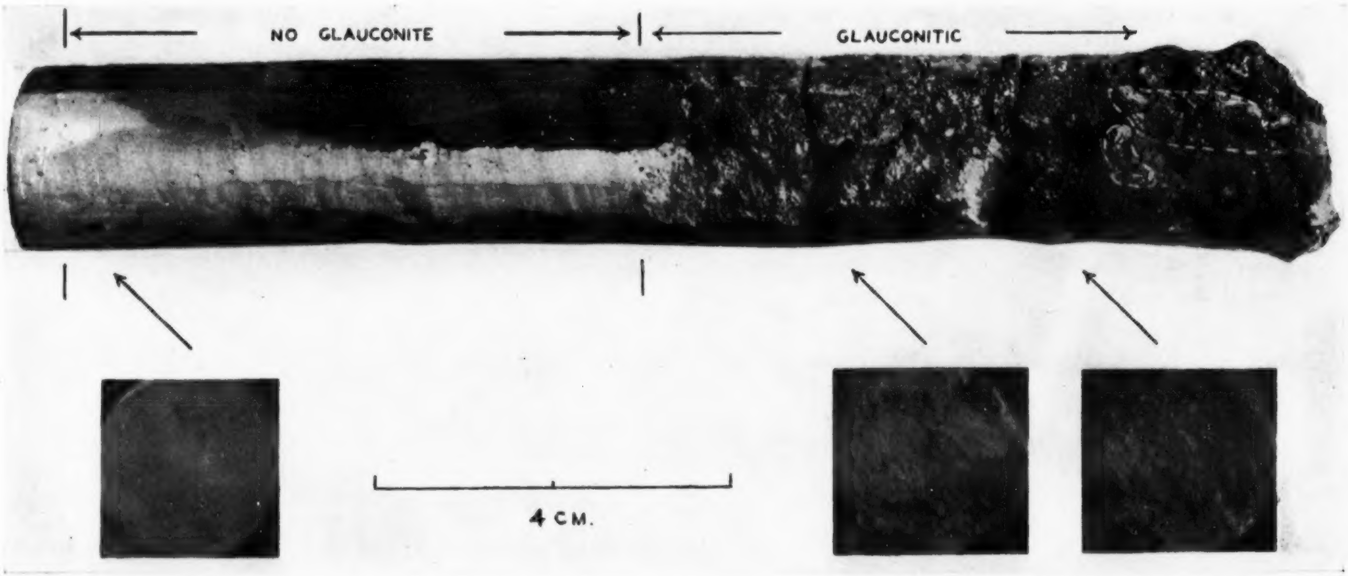

FIG. 8. *Glauconitic gravels.*—Core from station No. 121, typical of "stratified" area (Fig. 1). Top of core at right. White dashed lines delimit pebbles in upper coarse part of sediment. They consist of reworked Miocene shale, also granitic rocks. Important is complete absence of glauconite in lower part (left) of core. In overlying layer, however, soft, spongy type glauconite is well developed. Biotite is rare, but there are many alteration stages from biotite to glauconite.

however, is everywhere uniform. It is lithologically identical with sediments in the widely distributed "Mud" areas. Although the bottoms of the cores are generally the same color, gray or greenish gray, all the top parts are very definitely green, due to glauconite.

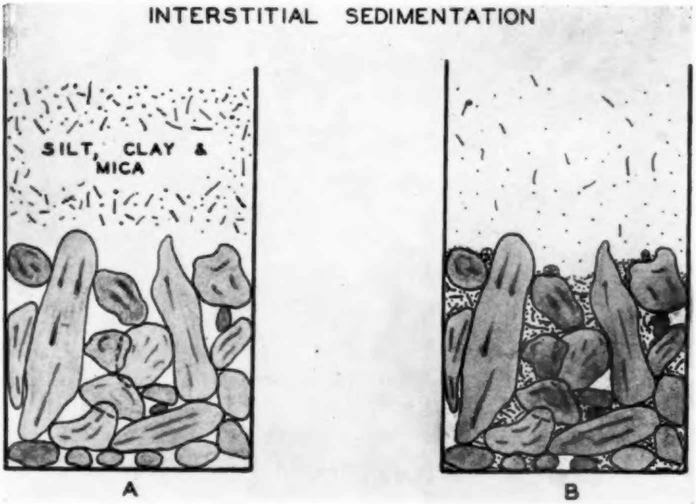

FIG. 9. *Interstitial sedimentation.*—
A. Coarse gravels having fairly large interstices.
B. Into interstices settle fine sediments consisting of silt, clay, and mica. Important characteristic is that large pebbles continue to remain in contact with each other. Foraminifers become entombed in silt. Thus coarse gravels deposited at former time may have associated with them fauna indicative of later time and different environment. Because an interstice may not have open connection with others, it may fail to fill with fine material. This is characteristic of process.

A map with more exact textural definitions of these sediments has been previously presented.[7] In that map the distribution of gravels is shown differently, but the present map is an interpretation of many added dredgings.

BIOTITE AND GLAUCONITE DISTRIBUTION

Definite changes in mineralogy take place coördinately with changes in color and mechanical composition of the sediments. Mineral changes giving the clue to the obvious relationship between glauconite and biotite make it evident that glauconite in the off-shore

[7] E. Wayne Galliher, "Sediments of Monterey Bay, California," *State Mineralogist of California Rept. 28*, Vol. 28 (1932), pp. 42–71.

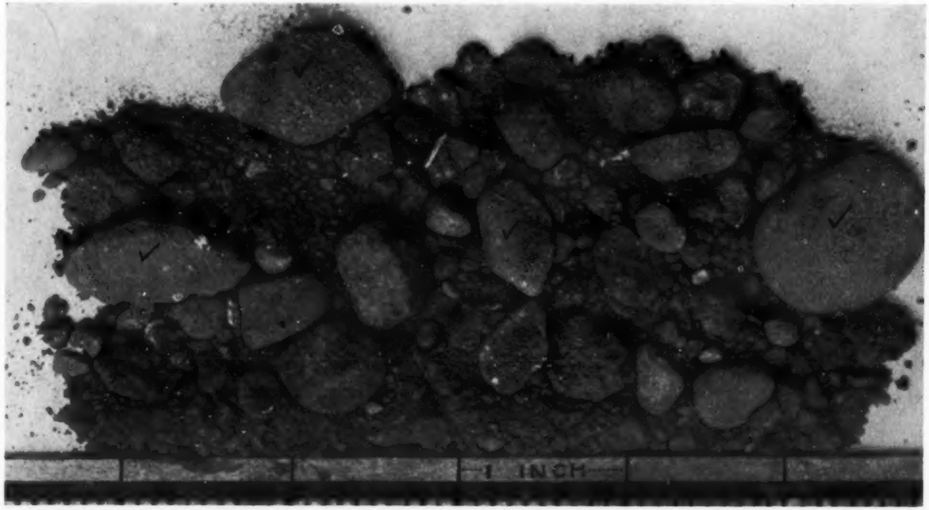

FIG. 10. *Mass sample of gravels.*—Mass sample of upper layer of "stratified" area from station No. 93 (depth 60 fathoms). Few pebbles marked by checks: hard, reworked Miocene siliceous shale. Remainder: granite and gneiss. Large pebbles, coupled with their poor sorting, indicate deposition in shallow, well agitated water, perhaps part of river delta. Glauconite abounds; formed principally from mica coming to rest on and around gravel subsequent to submergence to 60-fathom line.

sediments is the mineralogic equivalent of biotite in those near shore. To anyone dredging in the shallow-water area (0–100 fathoms), the following relationships are obvious.

1. Micas are found in few places between the strand line and 5 or 10 fathoms, for the water is too mobile to allow flaky forms to come to rest.

2. Instead, they are wafted farther out and deposited at a depth where there is less wave action. Below 5 or 10 fathoms, micaceous minerals are dropped on the bottom. They are especially plentiful in sediments lying between 20 and 30 fathoms. In Figure 1 areas where biotite is especially rich have been so designated. In general, they occur in either very fine sand or mud areas.

3. In the near-shore sediments the major part of the biotite is brown. This is particularly true in the southern end of the bay where Monterey Peninsula granite contributes detritus.

A certain amount of green mica is everywhere present, however, along with brown biotite. On superficial examination the green mica appears to be chlorite, but further petrographic work has shown that it is mainly green biotite. Its percentage in the sediments increases with depth and distance from shore and the percentage of brown biotite decreases correspondingly.

4. Glauconite begins occurring with biotite, at depths as shallow as 5 or 10 fathoms; coördinately, as the percentage of glauconite increases, the percentage of biotite, green and brown, decreases.

5. Finally, at about 50 fathoms, glauconite becomes very plentiful, especially in the vicinity of the granite, brown and green biotite nearly disappearing. Biotite is present in various stages of alteration.

PHYSICAL CHANGES FROM BIOTITE TO GLAUCONITE

STRUCTURAL AND DENSITY CHANGES IN MINERAL GRAINS

In the grains themselves lies the evidence proving that glauconite is altered biotite. From all samples containing glauconite, series of grains have been picked which show, step by step, changes occurring between unaltered brown biotite and typically developed green glauconite.

Structural changes taking place are shown in Figures 11–13. They represent about seven types, as follows.

1. Unaltered biotite. The biotite is, in general, dark brown in thin flakes and black in thick grains. This is particularly true of biotite derived from granite exposed at the southern end of the bay. The specific gravity is always greater than 3.0 and averages 3.05–3.1.

2. Biotite, partly altered to green, with some original brown re-

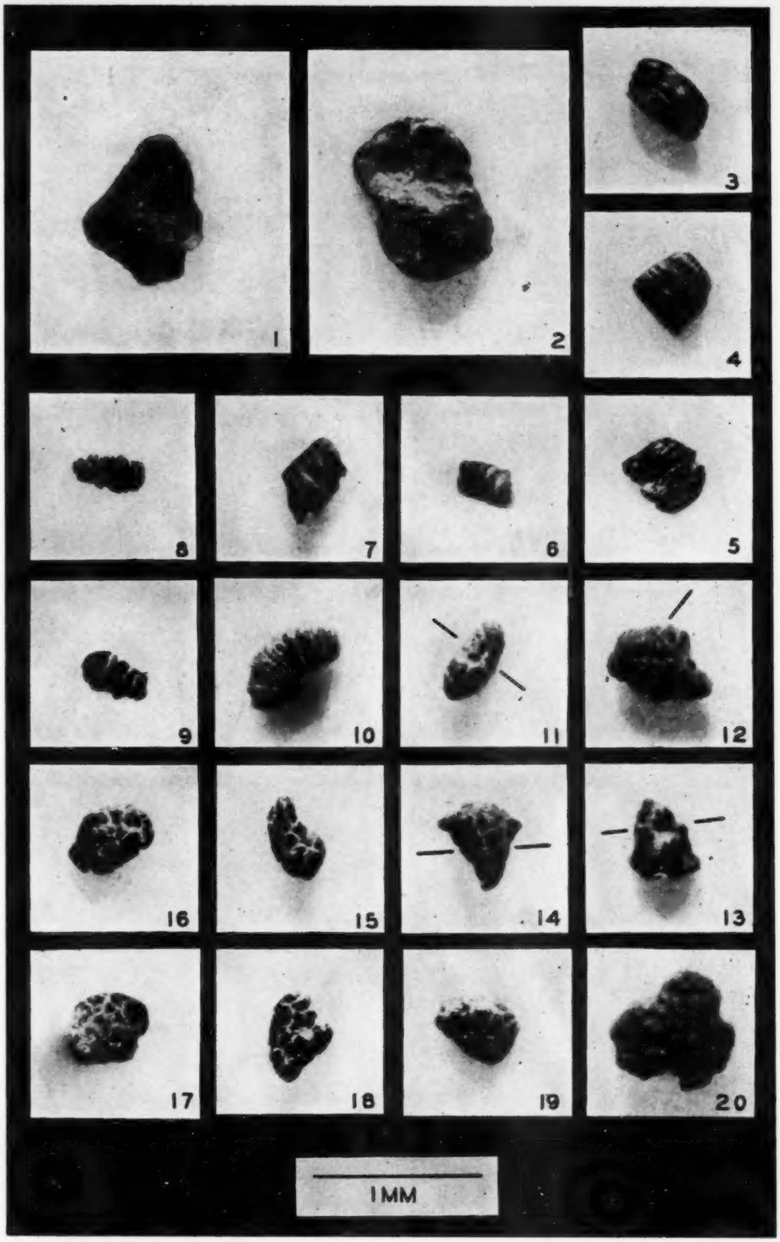

FIG. 11. *Biotite altering to firm type glauconite.*—Series of grains picked from sample No. 153 to show various stages in biotite-to-glauconite transition.

1. Biotite grain altered green around edge. Unaltered center brown.

2. Biotite entirely green. Alteration along cleavages causes irregularity and distortion of flaky surfaces.

3–9. Side views of biotite grains, showing alteration product (white) forming in cleavage planes and spreading grains into elongate bodies.

10. Accordion-like stage of grain where alteration proceeds more rapidly from one side. In specimens 3–10 plane of cleavage is at right angles to the paper.

11–14. Grains of biotite wherein alteration has cut across direction of cleavage as well as along it. Traces of cleavage indicated by lines. Although grains 13 and 14 have superficial resemblance to foraminifers, they develop independently of any organic body.

15–19. Typical glauconite grains with ramifying alteration. Reticulated pellets representing stage immediately preceding spongy, swollen stage shown last.

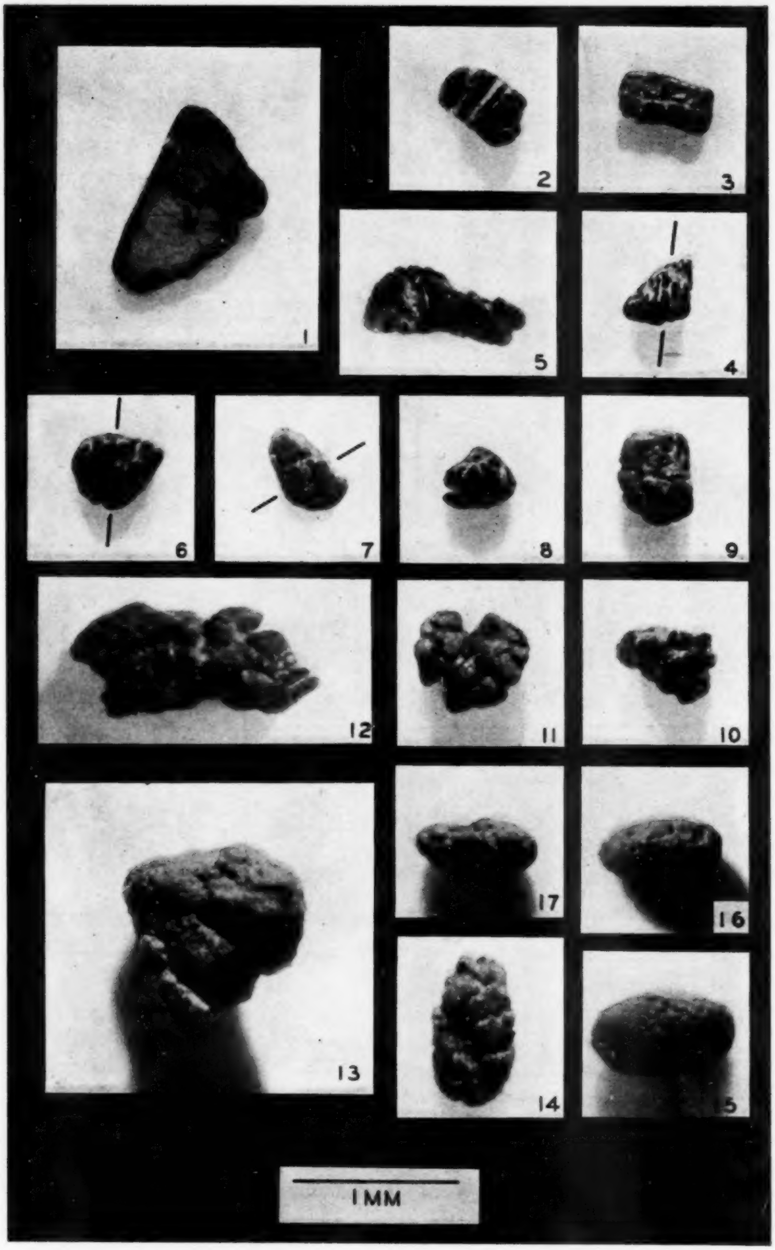

FIG. 12. *Biotite altering to spongy type glauconite.*—Series of grains from sample No. 128 showing transition stages of biotite-to-glauconite.

1. Biotite flake partially altered green. Center remains brown.

2. Swollen green biotite with alteration proceeding along cleavage planes.

3–6. Alteration cutting across, as well as along, cleavages, traces of which are indicated.

7–9. Stage of alteration in which nearly all characteristics of biotite are lost. Grains assume typical structure of glauconite and are still fairly firm.

10–17. Final soft, swollen, spongy grains of glauconite. Material easily abraded and as mud and sand go through digestive systems of worms, many coprolites are developed.

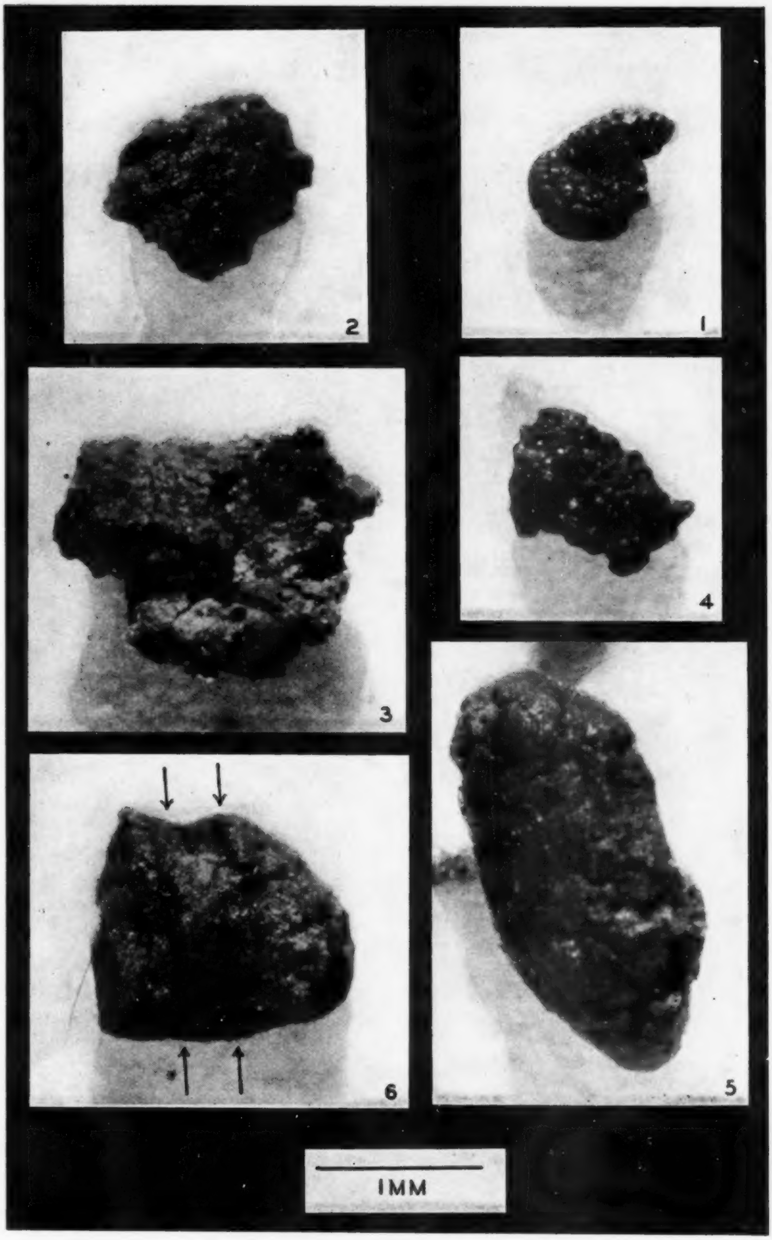

FIG. 13. *Spongy glauconite and glauconite coprolites.*—Spongy, swollen glauconite well represented in sample No. 117. Reticulated grain of photo 1 represents stage immediately preceding spongy stage, of photos 2–6.

Photos 3 and 4 give idea of high porosity of grains (broken to show internal structure).

Photo 5, large glauconite coprolite, probably of mud-dwelling worm.

Photo 6, broken coprolite showing cracks, the last vestiges of biotite cleavage. Rarely is this structure preserved to final stage.

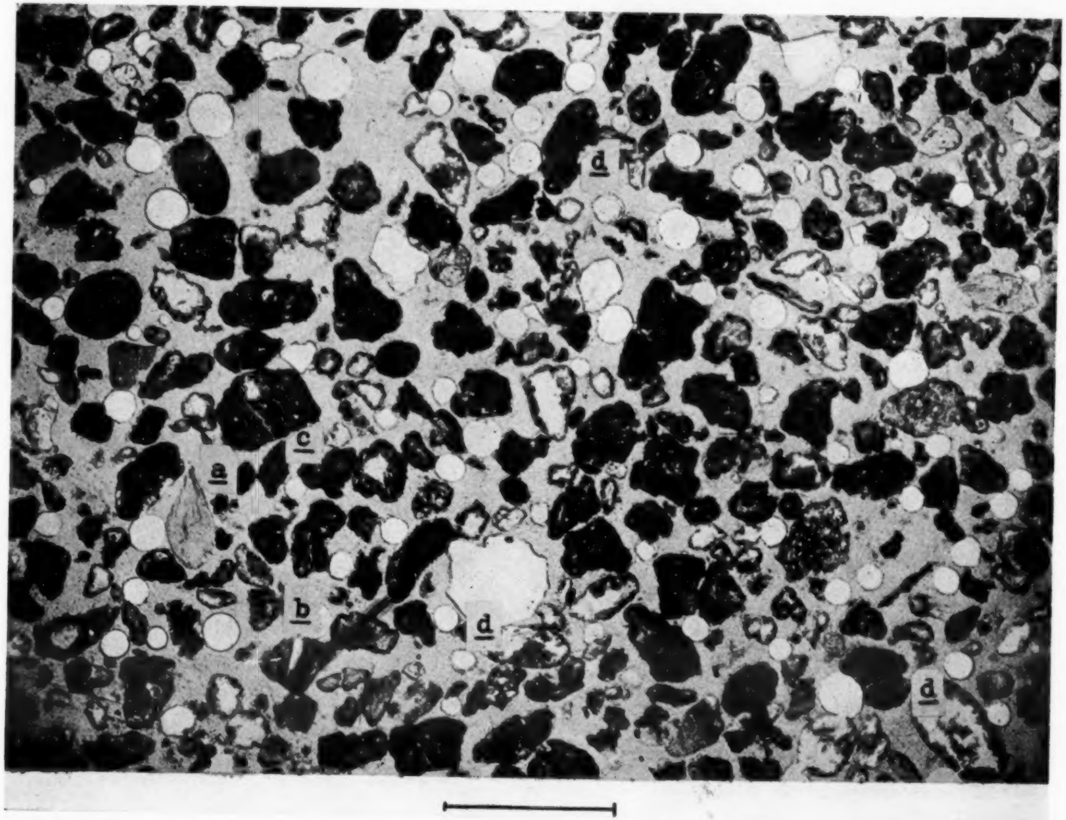

FIG. 14. *Biotite, altered biotite, and glauconite in thin section.*—Thin section of glauconite concentrate from station No. 128, showing many coprolites (*d*), so soft that grinding removed their centers. At *a:* brown biotite flake with cleavage plane nearly parallel with plane of section. At *b:* spreading accordion-like biotite grain with cleavage plates on end; green or brownish green. At *c:* glauconite grain in last stages, still showing irregular cracks, the only remaining traces of biotite structure.
Round transparent areas: bubbles in embedding medium. Line represents one millimeter.

maining (Fig. 11, 1 and 12, 1). Alteration proceeds from the edges toward the center. The results are, in some cases, flakes with brown centers completely surrounded by green borders.

3. Biotite, entirely green. In this stage a light green alteration product, powdery glauconite, forms progressively along cleavage planes (Fig. 11, 3). This is apparently the "chloritic" glauconite,[8] "fibrous glauconite,"[9] or "crystalline glauconite" described by several authors.

4. With increase in volume, accomplished by swelling along cleavages, the grains lose their micaceous form, becoming more or less rounded prisms (Fig. 11, 6).

5. Some grains become so swollen that they resemble accordions or caterpillars (Fig. 11, 10). It was this kind of grain, along with typical granular glauconite, that Mansfield[10] pictured in his report on New Jersey greensands. Grains with radial structure described by Cayeux[11] also belong here.

6. Glauconite forms across cleavage planes as well as along them. Distortion resulting from this process transforms the grains into varied and fantastic shapes. Some of them superficially resemble foraminifers, but they develop entirely independently of the shell of any organism. In only one grain out of all the 800–1,000 grains examined was there evidence that it had developed in the shell of a foraminifer, and in that particular case the shell was still around it.

Figures 11, 11 *et seq.* show the sixth stage. Although the grains appear to be shell-moulded, they have attained their form free from shell confinement. In this step the glauconite is still hard and firm and dark or bluish green. Its specific gravity varies considerably, averaging 2.6 or less.

7. Finally the grains swell, become porous or spongy, structurally very weak (Fig. 13), and uniformly light or yellowish green, losing practically all traces of the original biotite structure. Many are so swollen that they do not pass freely through digestive tracts of mud-dwelling worms. Consequently, when the organisms digest the sedi-

[8] J. E. Spurr, "Origin of Certain Ore-Deposits," *Econ. Geol.*, Vol. 10 (1915), p. 474. C. S. Ross, "The Chloritic Material in the Ores of Southeastern Missouri," *ibid.*, Vol. 11 (1916), pp. 289–90.

[9] J. K. Prather, "Glauconite," *Jour. Geol.*, Vol. 13 (1905), p. 511 and Pl. V. Assar Hadding, "The Pre-Quaternary Sedimentary Rocks of Sweden. IV. Glauconite and Glauconitic Rocks," *Lunds Universitets Årsskrift*, N. F. Adv. 2, Bd. 28: 1 (1932), pp. 114 and 117.

[10] G. R. Mansfield, "Potash in the Greensands of New Jersey," *U. S. Geol. Survey Bull.* 727 (1922), Pl. IV.

[11] L. Cayeux, "Contribution à l'étude micrographique des terrains sédimentaires," *Soc. Géol. Nord Mém.*, Vol. 4, Pt. 2 (1897), p. 164.

ment, chiefly mud, they mould the grains into coprolites (Fig. 12, 15). Many of these objects have been collected from organisms, principally worms. This type of material has been described elsewhere.[12]

The true specific gravity of the spongy material varies from 2.2 to 2.6. The apparent specific gravity is much smaller, being even less than 1.0 for many grains. They probably have increased to a size between ten and twenty times their original size, expansion taking place principally in a direction perpendicular to the original biotite cleavage. It is small wonder that various reports tell of glauconite occurring for the most part in broken foraminiferal shells. A very small flake of biotite sifted into a foram may swell and either fill the chambers of the shell or become so large that it breaks the test.

Green silt and clay derived from disintegrating glauconite gives mud areas a greenish cast. This loose material even penetrates cleavage cracks in feldspar, giving it a greenish color. Cayeux[13] ventured to call this sort of material pigmentary glauconite. Mansfield[14] has described flakes of glauconite in cracks of feldspar in New Jersey greensands. It is apparently a feature common to many localities.

At times a feldspar or quartz grain remains attached to a biotite flake although the latter has made considerable progress in altering. Such composite grains give a false impression that glauconite is growing out of quartz or feldspar. Remnant biotite cleavages in the glauconite, however, generally intersect edges of the other mineral at acute angles and, in thin section especially, demarcation between the two minerals is distinct.

Grains showing features of alteration from biotite to glauconite are abundant in greensand samples from many widely scattered localities: the Lutetian and Wimmelian of France, Cook Mountain and Navarro formations in Texas, Eocene of Martinez, Marysville Buttes, and Santa Teresa Hills, California, Temblor Miocene of California, Aquia formation of Maryland, Pliocene of West Java. The European material was collected by H. G. Schenck under the auspices of the C. R. B. Educational Foundation.

OPTICAL PROPERTIES OF TRANSITIONAL STAGES

There is some variability in the optical properties of the biotite. Most of the optical tests have been made on material used for chemical analysis; that is, biotite concentrated from granite of the Mon-

[12] J. Takahashi and T. Yagi, "Peculiar Mud-Grains and Their Relation to the Origin of Glauconite," *Econ. Geol.*, Vol. 24 (1929), pp. 838–52.

[13] L. Cayeux, *op. cit.*

[14] G. R. Mansfield, *op. cit.*, p. 140.

terey Peninsula. The average index of the fast ray, determined in many grains, is 1.60; it ranges from 1.59 to 1.61. The index of the slow ray averages 1.65 and ranges from 1.645 to 1.66. The mineral shows in thin section (Fig. 14) the characteristic pleochroism from yellow to brown or yellowish brown; the birefringence is high.

When the biotite turns green, the average index of the slow ray drops to about 1.63, but that of the fast ray apparently falls no lower than 1.59 or 1.60. Although the birefringence decreases to approximately 0.04, it may still be considered high. Pleochroism varies from none at all in some grains to the combination of green-to-yellowish or brownish green in others. Those showing no pleochroism are the more altered ones. They also have wavy extinction and show beginnings of the aggregate structure so characteristic of later stages. Some grains show uniform and wavy extinction at different ends.

As alteration proceeds and glauconite envelops and cuts through the lamellae, both birefringence and pleochroism decrease. The final stage may be described as a light green or yellowish green mineral without pleochroism, with low birefringence, an average index of refraction of 1.60 or 1.62 and aggregate polarization.

Just as there are a great many stages between green biotite and the final hydrated product, glauconite, there are consequently many optical characteristics corresponding with successive stages in development. It is, therefore, hazardous to give optical constants and rigid definitions for glauconite,[15] for they may not apply to all variations.

GEOCHEMISTRY OF GLAUCONITE

GENERAL CONSIDERATIONS

Several simple facts explain the alteration. In the first place, glauconite occurs, with rare exception, in close association with areas of quiet black muds and sands. In the second place, the black mud, called the sulphuretum, is an anaerobic environment, but oxidation processes are nevertheless carried out therein. There is nothing incredible about the fact that dehydrogenation is equivalent to oxidation and that it is an active anaerobic process.

An article on the sulphur cycle in sediments[16] gave the steps by which sulphur is oxidized to sulphate, the process liberating energy.

[15] C. S. Ross, "The Optical Properties and Chemical Composition of Glauconite," *U. S. Natl. Mus.*, Vol. 69 (1926), Art. 2. See also the controversy between A. F. Hallimond, "The Formula of Glauconite," *Amer. Mineralogist*, Vol. 13 (1928), pp. 589 and 590; and Hyrum Schneider, "A Study of Glauconite," *Jour. Geol.*, Vol. 25 (1927), pp. 289–310.

[16] *Op. cit.*, p. 54.

Similarly in glauconite, although it occurs in an anaerobic environment, practically all the iron is finally oxidized to the trivalent state, as chemical analyses show. In fact, when glauconitic sands and muds are dredged they reek with hydrogen sulphide. It is one of the strongest reducing agents, and a product of anaerobiosis. Yet glauconite grains in these samples are commonly flecked with, or some are even coated by, brown ferric hydroxide. The fact that glauconite is not homogeneous further refutes the idea of endowing it with a chemical formula.

It is suggested that the process of iron oxidation in the sulphuretum is accomplished, as with sulphur, by dehydrogenation following hydrolysis:

$$2FeO + H_2O = 2H + Fe_2O_3.$$

Fermentation processes, nitrate reduction and sulphate reduction may act as hydrogen acceptors in the sulphuretum, and the sum total effect of the dehydrogenation process is to liberate energy.

Oxidation may occur, of course, at the surface of the sediments. Organisms, principally worms, are apparently continually stirring the sediments, and it is possible that iron is also added to the spongier glauconite during its intimate contact with the ferric hydroxide developed in the surface layers. The addition is probably accomplished by base exchange of ferric iron for aluminium, perhaps also to a certain extent for the alkalies and alkaline earths. "*Halmyrolysis*," proposed by Hummel,[17] is a term sufficiently obscure to encompass all these reactions with perfect safety.

At the surface of the muds and sands, especially in the shallow water areas, oxidized materials are the rule. A striking occurrence in a shallow area is station No. 115 (Fig. 2, 2). It is a well washed sand in about 5 fathoms of water. Various kinds of micaceous minerals are brought to the ocean from the plutonic and metamorphic complex of the Santa Cruz Peninsula at the north end of Monterey Bay (Fig. 15). The minerals are unstable and the instability is being expressed by alteration soon after immersion in sea water. They are all altered or in the process of altering to glauconite and glauconite-like minerals. Steps in their transformation are identical with those found in transition mica-glauconite grains more generally distributed in deeper water throughout the bay.

A last fact concerns the alkaline environment in which alteration takes place. In general, anaerobic decomposition tends to increase

[17] K. Hummel, "Entstehung eisenreicher Gesteine durch Halmyrolysis," *Geol. Rundschau*, Bd. 13 (1922), pp. 50–78.

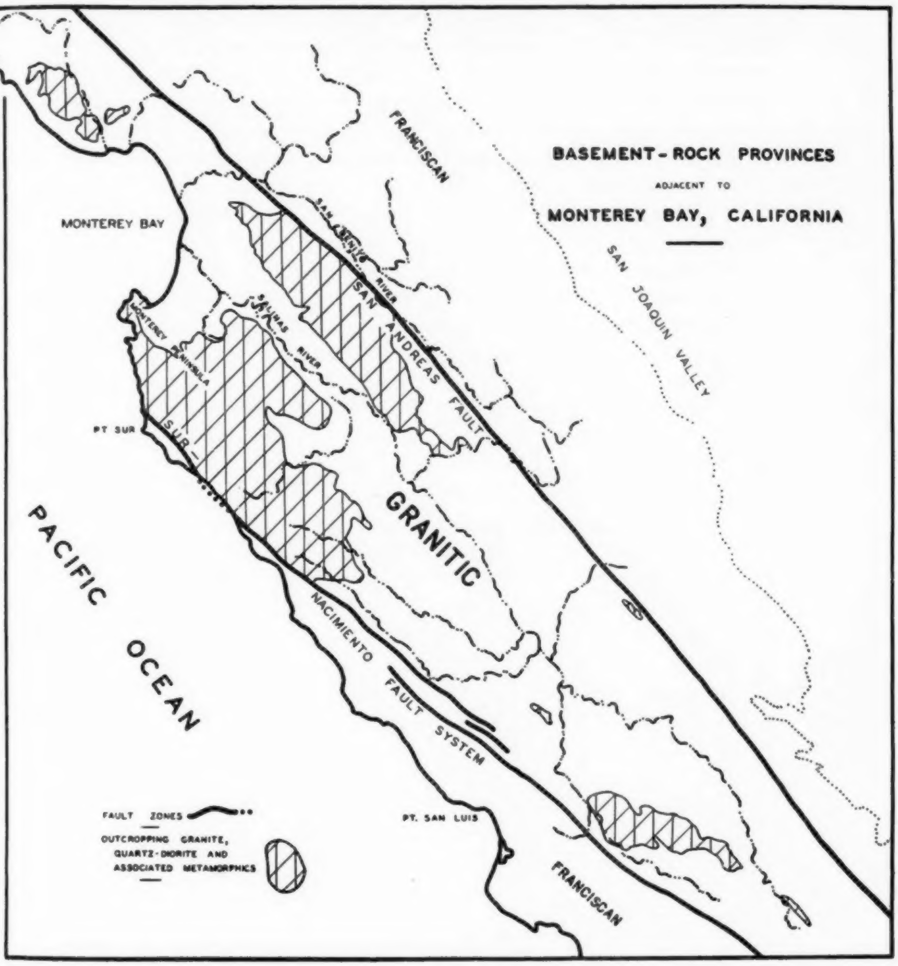

FIG. 15. *Source rocks for glauconite.*—Basement rocks surrounding Monterey Bay are plutonic rocks of granitic type and metamorphic rocks associated with them. Granite, granite aplite, granite porphyry, granodiorite, and quartz diorite are principal plutonic types exposed. Metamorphic rocks include biotite-schist, mica-schist, gneiss, and marble. Complex group of rocks derived from metamorphism of Paleozoic or pre-Paleozoic sediments, or both.

Franciscan basement rocks occur both inland and south from bay and south from it along coast. They include serpentine and other altered basic intrusives and some sediments.

Most detritus carried into bay comes from granitic province. Detritus from Franciscan rocks everywhere present, but in minor quantities.

Part of data furnished by California Division of Mines.

alkalinity and black muds sometimes reach a *pH* of 9 or 10; that is, they are very alkaline. Sea water itself is definitely and persistently an alkaline solution. Its *pH* remains about 8.0–8.3. Because of its high alkalinity and electrolyte content, it tends to alter silicates. In spite of the statement found in most textbooks on oceanography that potassium is withdrawn, inorganically, from sea water, such is not the case. The following data are treated more completely in a paper to be published later, but are summarized here: potassium salts soluble in fresh water are also readily soluble in sea water; the ocean is by no means saturated with potassium salts, and they are among the last to be precipitated on evaporation; silicate minerals and glass decompose in sea water with tendency toward removal of alkalies, alkaline earths and aluminium, accompanied by hydration.

Biotite decomposition follows a similar principle, and the chemical evidence is not very complicated. The manner in which the chemical transformation progresses may be shown by a series of chemical analyses.

TABLE I
ANALYSES SHOWING CHEMICAL TRANSFORMATION OF BIOTITE*
(Percentage)

	1. Biotite	*2. Firm Type Glauconite*	*3. Spongy Type Glauconite*
SiO_2	36.25	55.95	51.90
Al_2O_3	18.25	11.56	1.52
Fe_2O_3	6.35	9.99	27.98
FeO	17.09	2.02	1.26
MgO	9.01	6.77	4.67
CaO	0.79	3.95	0.89
Na_2O		0.61	0.53
K_2O	8.68	4.12	4.90
H_2O (minus)		1.60	2.10
H_2O (plus)	2.70	3.22	4.05
P_2O_5		0.18	0.11
Organic matter		Trace	Trace
Total	99.12	99.97	99.91

* Analyses made by Abbott A. Hanks, Inc., San Francisco.

CHEMICAL ANALYSIS

The analyses presented here include: (1) biotite concentrate from Monterey Peninsula granite; (2) the firm type of glauconite generally distributed in the bay, but especially plentiful near the granite body (station No. 153); (3) the spongy type of glauconite found in all samples, but best developed at stations 117, 128, 147, and 156 (the concentrate for analysis comes from station No. 128).

Comparing the analyses shows that with decrease in alumina, potash, and magnesia, there remain proportionately larger amounts of silica and iron oxides. Nearly all ferrous iron is oxidized to the ferric state. In spongy glauconite from station 128 there is apparently an excessive amount of iron, perhaps acquired when the material was mixed with limonite at the surface of the mud. Limonite is visible on all grains, on some confined to their surfaces, in others penetrating the spongy masses.

Excessive calcium oxide and silica in firm glauconite is due to admixture of about 7 per cent feldspar, quartz, and shell debris. About 48 per cent silica is more nearly correct for this analysis (No. 2).

Water in *spongy* glauconite nearly doubles that in biotite; hydration is probably the principal cause of its excessive cracking and swelling.

It is evident that most of the chemical problems of glauconite formation disappear. The greatest difficulty that Murray and Renard[18] encountered in their theory of glauconite genesis was to get the potash, supposed to be drawn from sea water, into the hypothetical iron-aluminium magnesium-silicagel. But even as late as 1912 Murray and Hjort[19] wrote: "The chemistry of its genesis is a complete mystery." They had been trying to build up a mineral, of course, instead of forming it by the break-down of another. Their theory has been used, incidentally, by Goldman,[20] to account for greensand beds of the geologic column.

Similar potash contents in biotite and glauconite are shown in many other analyses. In those of biotite compiled by Dana[21] and Clarke,[22] potash ranges from 6 to 10 per cent. Similarly, their glauconite analyses, and Hallimond's[23] as well, show potash ranging from 6 to 8 per cent; those of numerous others, from 2 to 8 per cent.

A comparison of the same analyses shows lower content of alumina in glauconite than in biotite. That of the latter may vary from 12 to 20 per cent and the former from 4 to 12 per cent. Correspondingly, magnesia may vary from 5 to 20 per cent in biotite and 2 to 4 per cent in glauconite.

[18] *Op. cit.*

[19] John Murray and Johan Hjort, *The Depths of the Ocean* (1912), p. 189.

[20] M. I. Goldman, "General Character, Mode of Occurrence, and Origin of Glauconite," *Washington Acad. Sci. Jour.*, Vol. 9 (1919), pp. 501–02 (abstract).

[21] Dana, *System of Mineralogy* (1904), pp. 630 and 684.

[22] F. W. Clarke, "Analyses of Rocks and Minerals, *U. S. Geol. Survey Bull. 591* (1915), pp. 93, 332, and 340.

[23] A. F. Hallimond, "On the Constitution of Glauconite," *Mineralogical Mag.*, xix (1922), p. 330.

The analyses, analysts, and localities from which data come are varied. But varied though they are, similarities in biotite and glauconite composition are always apparent. It must be emphasized that *in the marine environment silicate minerals are being decomposed, not built up*. The biotite group of micas alone can supply the elements found in glauconite; or, stated in a simple way, biotite is a silicate of *K*, *Mg*, *Fe''*, *Fe'''*, *Ca*, and *Al;* glauconite, its alteration product, is merely a hydrous silicate of the same elements.

GEOLOGIC FACTORS OF GLAUCONITE FORMATION

SOURCE ROCKS

Clastic material contributed to the bay comes chiefly from rocks of granitic character and schists and gneisses closely associated with them (Fig. 15). Well exposed at the northern tip of Monterey Penin-

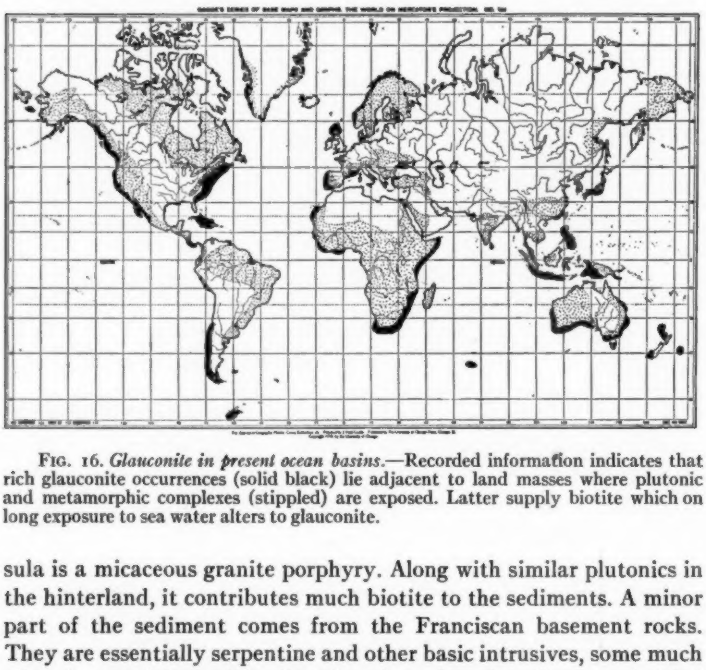

FIG. 16. *Glauconite in present ocean basins.*—Recorded information indicates that rich glauconite occurrences (solid black) lie adjacent to land masses where plutonic and metamorphic complexes (stippled) are exposed. Latter supply biotite which on long exposure to sea water alters to glauconite.

sula is a micaceous granite porphyry. Along with similar plutonics in the hinterland, it contributes much biotite to the sediments. A minor part of the sediment comes from the Franciscan basement rocks. They are essentially serpentine and other basic intrusives, some much altered, associated with altered and unaltered sediments, bedded cherts, and limestones. Although Franciscan detritus is found in all parts of the bay, it is everywhere a minor constituent—*the dominant*

detritus is granitic. The close association of glauconite with this type of province is very important, for, by analogy, certain facts may be emphasized explaining its present distribution in ocean basins. The regional picture is also useful when explaining the occurrence of glauconitic rocks in the geologic column.

In Figure 16 the occurrences of glauconite in Recent marine sediments have been compiled from different sources.[24] The map shows that glauconite occurs adjacent to land masses where plutonic or metamorphic complexes are exposed. These rock types are, of course, excellent sources of biotite and other mica minerals. When dumped into the ocean they become potential glauconite and glauconite-like minerals. In this respect it is not at all surprising that the *Challenger* Expedition[25] found:

> Glauconite is almost always accompanied by quartz, orthoclase often kaolinized, white mica, plagioclase, hornblende, magnetite, garnet, epidote, tourmaline, zircon, and fragments of ancient rocks, such as gneiss, mica-schists, chloritic rocks, granite, diabase, etc.

For these are the minerals of plutonic and metamorphic complexes, and it would be most unusual if glauconite, the altered biotite, were not found with them. Apparently because they did not find the complete series of mica-to-glauconite stages, the same authors[26] said:

> In many samples of Green Muds and Sands are numerous minute particles about the same size as the glauconite grains, and having the same mammillated surface, of a brownish or green color, but these from their internal structure are apparently highly altered grains of crystalline, schistocrystalline and other rocks.

And that they did not realize that biotite can supply the necessary potassium, as well as iron, for glauconite formation is definitely implied in the latter part of the following statement:[27]

[24] They include, among others:
John Murray and A. F. Renard, *op. cit.*
L. W. Collet and G. W. Lee, "Recherches sur la glauconie," *Proc. Roy. Soc. Edin.*, xxvi (1906), p. 238; Shoshiro Hanzawa, "Preliminary Report on Marine Deposits from the Southwest North Pacific Ocean," *Records Oceanographic Works Japan*, Vol. 1 (1932) pp. 59–77.
E. M. Thorpe, "Descriptions of Deep-Sea Bottom Samples from the Western North Atlantic and the Caribbean Sea," *Bull. Scripps Inst. Ocean.*, Tech. Ser., Vol. 3 (1931), pp. 1–31.
M. J. Thoulet, "Étude bathylithologique des cotes du Golfe du Lion," *Ann. Inst. Océan.*, t. IV (1912), fasc. VI.

[25] John Murray and A. F. Renard, *op. cit.*, p. 383.

[26] *Op. cit.*, p. 380.

[27] *Op. cit.*, p. 389. See also, for a corresponding statement: J. Murray and E. Philippi, "Die Grundproben der Deutschen Tiefsee-Expedition," *Wiss. Ergebn. d. Deutschen Tiefsee-Exped. auf dem Dampfer "Valdivia," 1898–1899*, Bd. X (1908), p. 176.

It was pointed out that glauconite was always associated with terrigenous minerals, and in particular with orthoclase more or less kaolinized and white mica, and with the debris of granite, mica-schists, and other ancient rocks. We cannot fail to be struck with these relations, for it is just those minerals and rocks that must give birth by their decomposition to potassium, derived from the orthoclase and the white mica of the gneisses and granites.

Thus when the facts assembled by Murray and Renard are reinterpreted, they point to the conclusion that granitic and metamorphic complexes provide a rich source of biotite which can be transformed into glauconite under certain conditions of submarine exposure. These are now considered in the light of their work and in regard to the detailed facts known about Monterey Bay.

TIME FACTOR

These men explained why there is a long stretch of comparatively glauconite-free sediments off the east coast of South America, although plutonic and metamorphic complexes are exposed inland. Their observations concern the rate at which material is being deposited and its subsequent exposure in the environment where it alters. They said:[28]

Wherever there is a large quantity of ferric hydrate in a terrigenous deposit, as off the Brazilian shores, or whenever the deposit is chiefly made up of river detritus that bears evidence of having accumulated at a rapid rate, glauconitic matter is either absent or developed to a very small extent. . . . On the other hand, when there is a large number of the fragments of ancient rocks that have apparently been for a long time exposed to the action of sea-water, and have consequently undergone much alteration, then glauconite grains . . . are usually abundant. . . . These conditions are as a rule met with along high bold coasts removed from the embouchures of large rivers. . . .

A similar set of observations in the bay, and a directed line of reasoning, indicate that the presence of glauconite in a sediment depends on the length of the diagenesis period of its parent mineral biotite. For instance, near shore and down submerged channels of the bay (Fig. 1) biotite dominates over glauconite. In fact, in the main east-west channel no glauconite at all has been found. Much sediment is also dropped near shore. Sand is deposited close in, mud farther out on the shelf and down channels. Only a small amount of mud is carried to the extreme western edge of the shelf.

It seems that because of the rapidity of deposition in near-shore and channel areas, biotite can not alter to glauconite; that is, before time has elapsed for alteration to take place sediments are covered

[28] John Murray and A. F. Renard, *op. cit.*, p. 236.

and protected from overlying water. Where sedimentation is slow, the change has time to occur before burial. The statements are borne out by facts about the "Stratified" or gravel area (Fig. 8). In this connection F. P. Shepard emphasizes the fact that coarse sediments are commonly found around the edges of continental shelves. He said:[29]

> Gravel, boulders, and other coarse sediments are found commonly off glaciated coasts, also around submarine ridges, and in a surprisingly large number of places along the outer margin of the shelves.

His explanations of the distribution include: (1) deposition of material on the outer shelf by powerful rivers during Pleistocene time when sea level was lowered by accumulation of ice on land; (2) lack of covering of the material by finer sediments of a later generation; (3) glaciation of the shelf to yield coarse glacial sediment; (4) landsliding,[30] such as might occur down the sides of the deep submarine canyon developed in Monterey Bay. Recently in a letter Shepard suggested that the change of level indicated by the stratified core indicates "principally a sea-level change."

As to the last point, it can only be said that in some places the California coast has risen in very recent times and in others subsided. Certainly it has not acted and is not now acting as a unit. The best that can be said about the core (Fig. 8) in this respect is that it contains evidence of a differential downward movement between the time of deposition of mud of the lower half and the time the bottom of the bay reached its present position.

The possibility of landslides may be eliminated, since the gravel is distributed well up on the continental bench and on canyon sides, and there is no place on the bench whence the material could have slid.

As for the glaciation point, the evidence indicates that the California coast range in this vicinity was not subjected to glacial activity during the Pleistocene. According to Reed,[31] "Glacial deposits in California are limited to some of the higher ranges."

The other two suggestions offered by Shepard deserve considerable attention, for they are an approach to the solution of an interesting physiographic problem of the west coast, namely, the submerged canyons. Evidence presented by cores not only substantiates his suggestions, but also brings out a principle that has received scant attention. It is the principle of *interstitial sedimentation*.

[29] F. P. Shepard, "Sediments of the Continental Shelves," *Bull. Geol. Soc. America*, Vol. 43 (1932), p. 1038.

[30] F. P. Shepard, "Canyons Beneath the Seas," *Sci. Monthly*, Vol. 37 (1933), p. 38.

[31] R. D. Reed, *Geology of California*, Amer. Assoc. Petrol. Geol. (1933), p. 258.

The process called interstitial sedimentation has been observed in many types of settling basins, artificial as well as natural. It is shown diagrammatically in Figure 9. Of bay sediments core sample No. 121 (Fig. 8) may be used as an example, for it is representative of the "Stratified" area. The upper part of the core is a silty gravel, so designated because it consists of two fractions. The major fraction is a gravel derived from granite, gneiss, Miocene siliceous shale, and some basalt. Particles range from 0.5 mm. to 20 mm., with more than half of these varying from 2 to 20 mm. The coarse grains are in direct contact with each other, rarely with silt intervening.

This coarse fraction has characteristics of material deposited in well agitated water. Figure 10 shows a mass sample of the sediment taken with a grab sampler from station No. 93, depth 60 fathoms. Its relatively poor sorting suggests a river gravel. Certainly there is no current now operating in the bay which might carry and deposit such a sediment at this depth. Data collected during the past 6 years by the Hydrobiological Survey, Hopkins Marine Station, California, show that the water lies in nearly static layers. What motion there is may be described as very slow upwelling. Layers range in temperature from about 4°C. in the deepest parts of the channels to about 15°C. near the surface.

Silt, constituting about 20 per cent of the silty gravel unit, is generally distributed on the gravel particles or packing the interstices between them. Silt does not hold the large grains apart nor keep them from being in direct contact with each other. In brief, the silt has an appearance of having settled into the interstices between coarse particles. In addition to silt, there are, of course, small amounts of clay, foraminifers, and mica, part of which has altered to glauconite. These materials have not yet been deposited in sufficient quantity to cover completely the submerged gravels.

Moreover, the material underlying the gravel is mud, lithologically identical with sediments occurring in the "Mud" areas. The bottom of this layer has never been reached; it is consistently *non*-glauconitic and contains fairly large amounts of fresh, brown, unaltered biotite.

Fossils in the two layers deserve more attention. The species of *Foraminifera* preserved in lower parts of the cores are all found living to-day. They live in a neritic environment (30–100 fathoms) bordering on littoral. Those found in the overlying gravel are neritic bordering on bathyal (100 fathoms or more). The paleontologic character of a core sample may be briefly described as follows.

Lower portion (silt and clay).—*Foraminifera* are neritic bordering on littoral. They are characteristic of assemblages found about the 30-fathom line and rarely below that. They include *Elphidium*, *Nonion*, *Eponides*.

Top portion (silty gravel and sand).—*Foraminifera* are neritic bordering on bathyal. They are characteristic of their present environment, the 100+ fathom line. They include among others *Cassidulina, Nonion, Bulimina ovata.*

In other words, there has been a differential downward movement of approximately 70 fathoms, or more, at this place in Monterey Bay since the deposition of the lower part of the core. The last movement may have been near the end of Pleistocene time, or closing it.

Downward movement of the bay, bringing these gravels to depths where only fine sediments are carried, has been succeeded by very slow deposition of the silt, clay, and mica which have settled into the interstices of the gravel (Fig. 9, A). Such slow sedimentation has allowed biotite time to alter, the result being a silty gravel carrying glauconite (Fig. 9, B). Briefly summarized, the history told by a core sample is something like this.

1. Deposition of the lower silt in shallow water, about 30 fathoms, sediment accumulating so rapidly that the biotite could not alter
2. Deposition of gravel in very shallow, well agitated water, probably as part of a river delta
3. Differential downward movement of the sea floor to its present position
4. Deposition of fine material in interstices of the gravel. Deposition so slow that the biotite has had time to become glauconite. Some *Foraminifera* living in this deep-water environment have become entombed in shallow-water gravels, along with interstitial silt, mica, and glauconite.

Perhaps periodic dredgings continued in this and other localities will give a quantitative control of the time factor in glauconite genesis, particularly if the localities are in regions where definite information may be obtained as to duration, volume, and intermittency of sediment deposition. Meanwhile the conclusion of the *Challenger* Expedition[32] will continue to apply, even though its significance may seem altered in the light of new facts.

Where the detrital matters from rivers are exceedingly abundant, and where there is apparently a rapid accumulation, glauconite, though present, is relatively rare; on the other hand, along high and bold coasts where no rivers enter the sea, and where accumulation is apparently less rapid, glauconite appears in its most typical form and greatest abundance.

SUMMARY

In Monterey Bay, California, glauconite replaces biotite in sediments as they are followed off shore to deeper water.

Most of the sediments are derived, directly or indirectly, from a granite and metamorphic basement complex.

From any given sample containing glauconite, series of grains may be picked, showing the transition from biotite to glauconite. Flat flakes of brown biotite become inflated, spongy grains of glauconite.

[32] *Op. cit.*, p. 382.

Optical properties of intermediate biotite-glauconite stages show progressive changes. Moreover, the specific gravity drops gradually from stage to stage.

In changing to glauconite, biotite loses some aluminium, potassium, and magnesium; it gains water, and most of the iron is oxidized. Factors affecting these changes are: (1) the alkaline solution, sea water; (2) conditions operating in the anaerobic black muds and oxidized layers overlying them.

Slow sedimentation in parts of the bay provides a long diagenesis period for biotite alteration.

The regional problems of glauconite occurrence are explained by the fact that it forms from biotite.

1. Glauconite is rarely found in deep-sea deposits, for most micaceous minerals come to rest around continental shores before reaching great depths.

2. Glauconite is found near land masses where plutonic and metamorphic rocks are exposed. They erode slowly, contribute biotite to adjacent ocean basins, and the biotite alters to glauconite.

3. Glauconite composition, especially potash content, varies from place to place, for it depends on the tenor of potassium in biotite.

4. Glauconite should be, and is, universally distributed, for it is formed from a prominent and widely distributed rock-forming mineral, biotite.

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JEFFERSON ISLAND SALT DOME, IBERIA PARISH, LOUISIANA[1]

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ABSTRACT

Jefferson Island, an elevation on a dry plain, is one of the Five Islands of Louisiana. The salt dome is under Jefferson Island and Lake Peigneur; the mound was produced by a salt spine, and the lake by subsidence due to solution of a flat table of salt.

More than 250 salt exploration, oil exploration, and sulphur exploration and producing wells have been drilled on this dome.

Salt was discovered in 1894 in the drilling of a water well, and sulphur was discovered in 1929 in an oil test. The salt is mined from a depth of 800 feet in the salt spine. The sulphur is mined from a deposit between two faults in the cap rock at depths ranging from 600 to approximately 900 feet.

More than 2,225,000 long tons of salt have been produced by the Jefferson Island Salt Mining Company, and more than 500,000 long tons of sulphur have been produced by the Jefferson Lake Oil Company, Incorporated, since 1932.

Several geophysical surveys have been made on Jefferson Island dome. As a result of the first survey, an electrical one, sulphur was accidentally discovered at a depth of 660 feet in a supposedly deep flank oil test. Later, both torsion-balance and seismograph surveys were made for the purpose of outlining the cap-rock area of the dome.

Evidence tends to show that the original cap rock of the dome is of sedimentary origin; however, solution of the salt, as shown by the subsidence of the lake bottom and by drilling, indicates that at least a portion of the cap rock immediately adjacent to the salt is of residual origin.

The novel necessity of mining sulphur in the middle of the lake involved several new engineering problems. A floating barge was developed for the drilling of the sulphur wells. The power plant is situated on the shore of the lake. The hot water, steam, air, and sulphur lines are carried to the point of mining operations by means of a trestle. The Frasch process is used in the mining of sulphur. Liquid sulphur from the wells in the lake is pumped to the shore, where it is allowed to cool and solidify in the large vats. It is then blasted down and loaded into cars for shipment.

INTRODUCTION

Jefferson Island is one of the famous Five Islands of Louisiana. These islands, which are elevations of land surrounded by marsh on low land, are in a straight line extending S. 49° E., and are as follows: Jefferson Island, Avery Island, Weeks Island, Cote Blanche Island, and Belle Island.

Their line of direction is from Lake Peigneur, in Iberia Parish, to the mouth of the Atchafelaya River, in St. Mary Parish.

Wells have shown that there are great masses of salt under each

[1] Manuscript received, August 21, 1935.

[2] General superintendent, Coastal Sulphur Company, Box 517. The writer is especially indebted to Cyril K. Moresi, State geologist, Department of Conservation, New Orleans, Louisiana, for the information furnished in the writing of this paper, and to Donald C. Barton for much helpful criticism.

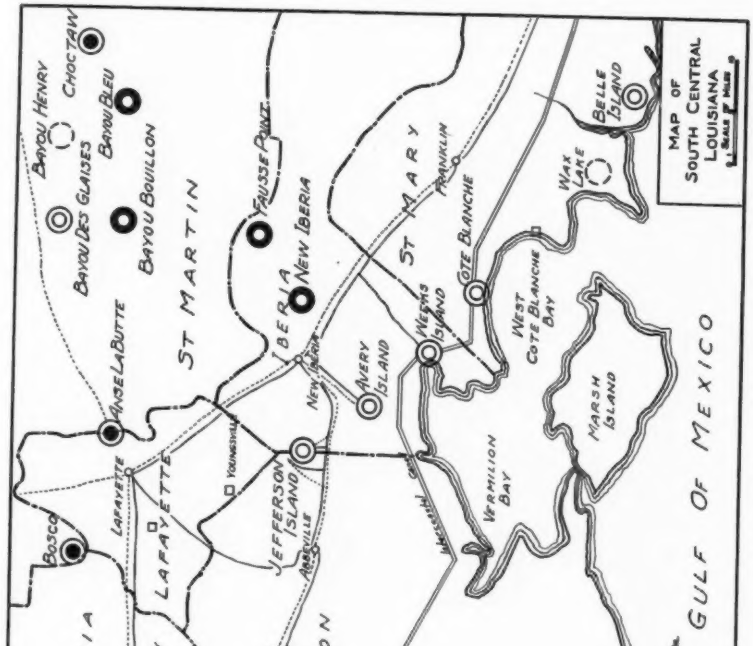

FIG. 1.—Map showing salt domes of south-central Louisiana.

of these islands. Only one of the Five Islands has had an important showing of oil, namely, Belle Island, and only one, Jefferson Island, has yielded sulphur. Belle Island has indications of sulphur; Jefferson Island has indications of oil. Salt is being mined at Jefferson Island, Weeks Island, and Avery Island.

LOCATION OF JEFFERSON ISLAND SALT DOME

Jefferson Island is about 10 miles west of New Iberia, in the southwestern part of T. 12 S., R. 5 E. A good gravel road is maintained to the salt-mine plant located at Jefferson Island on the south side of the lake. The sulphur-mine plant is at Barba, Louisiana, on the northwest side of the lake, and is reached by a 2-mile gravel branch road from the New Iberia-Abbeville concrete highway. The salt mine is served by a branch of the Missouri Pacific Railroad, and the sulphur mine by a branch of the Southern Pacific.

PHYSIOGRAPHY

In the strict sense of the word, Jefferson Island should not be called an island, because it is an elevation on a dry plain. Its maximum elevation is 75 feet above the surrounding plains (Fig. 2). In contrast to the other islands of the group, it has a very smooth contour, except for the side which faces the lake, where subsidence, together with wave action, has formed a bluff about 30 feet high. Part of the bluff has been moved by hydraulic means and washed into the lake to provide an area for the present salt mine.

The genesis of Lake Peigneur was not associated in the minds of geologists with Jefferson Island until comparatively recent times. As late as 1911, it was considered by Mann and Kolbe[3] to have been formed by the meandering of the Mississippi River.[4]

It was formerly believed that the salt stock was only under the mound of Jefferson Island. However, it has been definitely proved by wells that were drilled in 1928 that fully seven-eighths of the salt mass is under Lake Peigneur. The elevation of Jefferson Island was formed by a small spine of salt which is of a higher elevation than the main salt mass, and Lake Peigneur was formed by subsidence caused by the dissolving of the upper end of the salt stock by migratory waters.

The flora of the island is totally unlike that of the surrounding

[3] C. J. Mann and L. A. Kolbe, "Soil Survey of Iberia Parish, Louisiana," *U. S. Bur. Soils Field Operations 1911, 13th Rept.* (1914).

[4] H. V. Howe and C. K. Moresi, "Geology of Iberia Parish, Louisiana," *Louisiana Dept. Conservation Geol. Bull. 1*, p. 58.

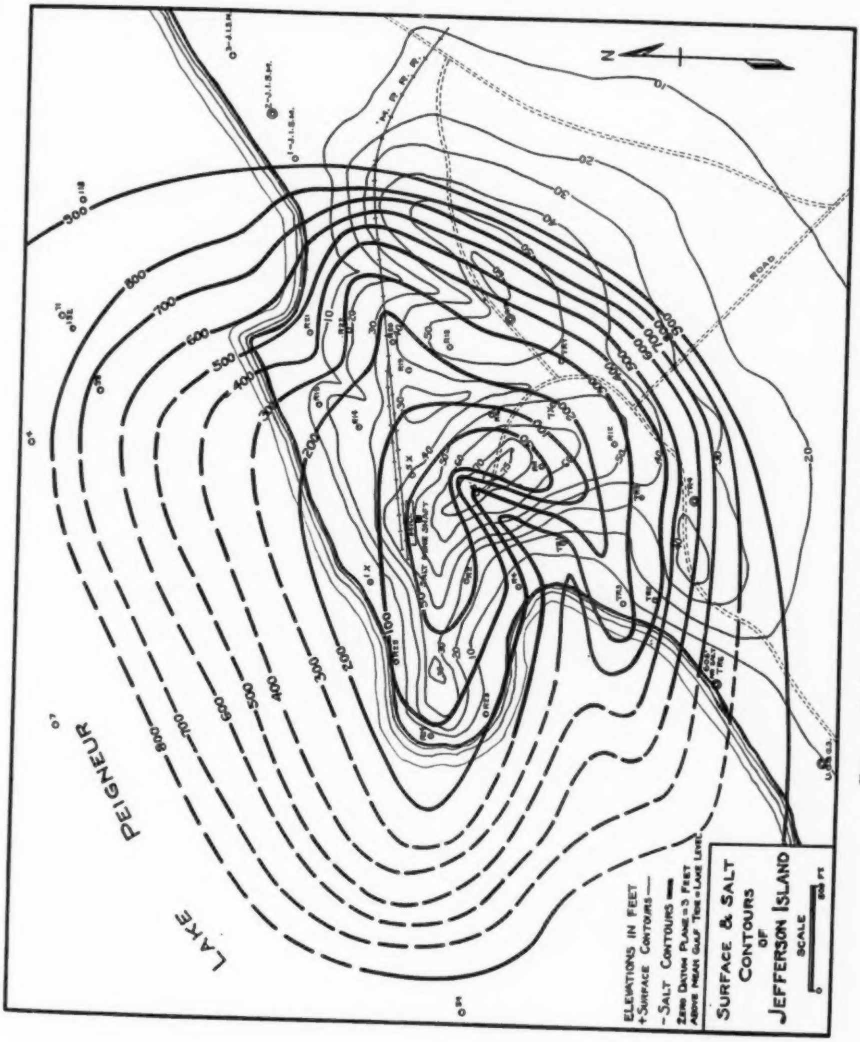

FIG. 2.—Surface and salt contours of elevated part of dome.

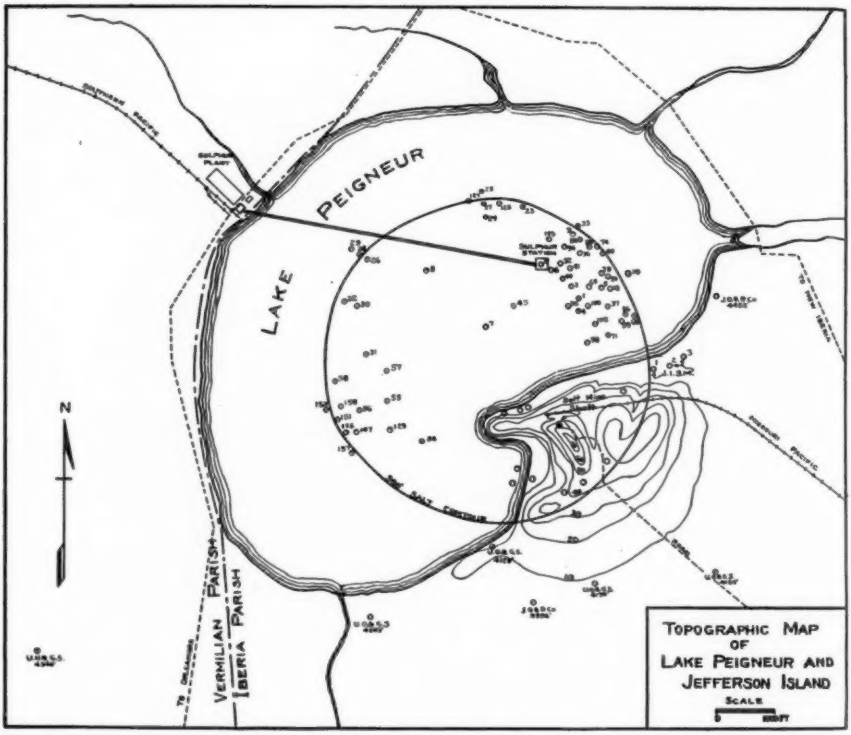

FIG. 3.—Topographic map of Lake Peigneur and Jefferson Island.

territory. It is much like that of the bluff lands in the northern part of the state. For an interesting discussion of this, see Darby.[5]

Lake Peigneur is exactly 2 miles long and 1 mile wide, with an average depth of 4 feet, and a maximum depth of 7 feet, with a water elevation of approximately 3 feet above mean gulf tide. In the early days, it was reported to have a depth ranging from 15 to 30 feet; however, the lake is fast filling up with sediment washed in from the surrounding lowlands.

The area of the lake is 1,400 acres. The total area of the dome at the 900-foot contour is 543 acres (Fig. 3). The dome has a uniform radius of 2,750 feet at this contour. The mound of Jefferson Island covers an area of about 100 acres. The plains surrounding the island are 10–14 feet above mean gulf tide, and are now used mainly for the cultivation of cane.

EARLY HISTORY OF JEFFERSON ISLAND

The island, as early as 1818, had been known as Cote Carline, but later it was variously known as Dupuy's Island, Miller's Island, and Orange Island.

Very early, the beautiful scenery and majestic view from the island attracted the attention of Joseph Jefferson, the famous actor. He built a winter home there, which stands to this day, and in recognition of this the island was renamed Jefferson Island.

There are three industrial chapters in the history of this island, namely, salt, oil, and sulphur developments. The period of discovery is not yet ended, as the dome still has mineral possibilities.

SALT EXPLORATION AND DEVELOPMENT

Salt was found at a depth of 334 feet in 1894 in a water well which was being drilled for Jefferson a short distance from his home. This was the first indication of salt in the mound. This hole was later drilled to a depth of 2,186 feet by A. F. Lucas, and was still in salt at this depth when it was abandoned. During 1897, 8 holes were drilled, of which only 4 reached salt. The drilling was then discontinued until 1919, when C. J. Webre, under the management of Lawrence Jones and J. L. Bayles of Louisville, Kentucky, continued the drilling. Thirty-six holes were drilled, proving that a great part of the salt is above the 200-foot contour, and that the salt rises to a height within 69 feet of the surface (Fig. 2).

After the exploration was completed, the Jefferson Island Salt

[5] William A. Darby, *The Emigrants' Guide to the Western and Southwestern States of Louisiana, with Map*, New York (1818).

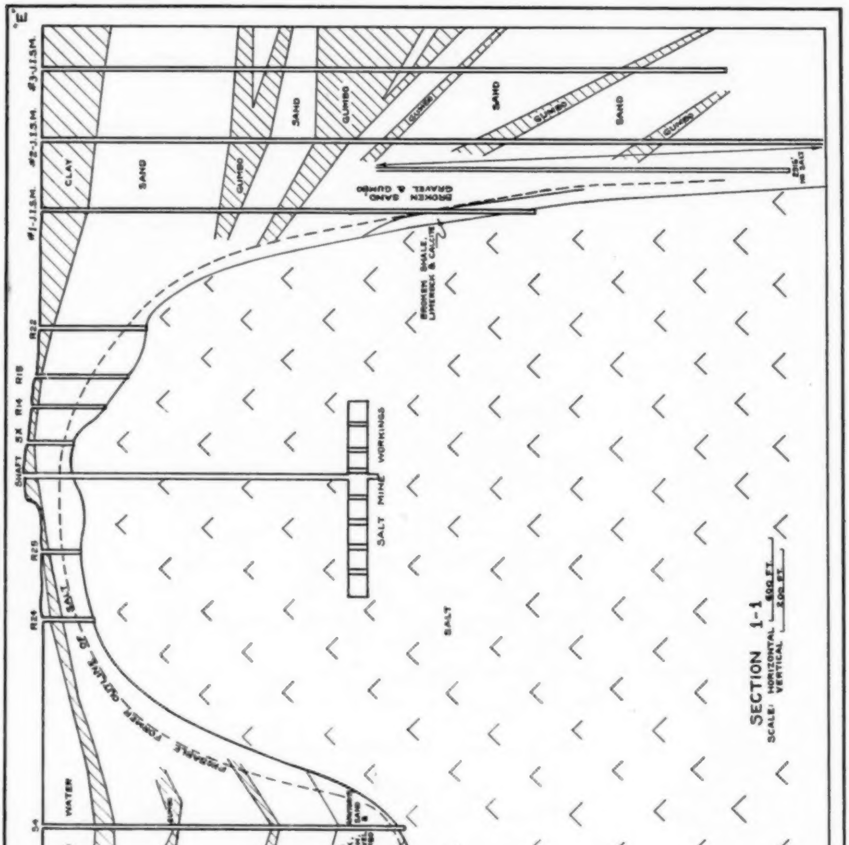

FIG. 4.—East-west section through Jefferson Island, showing salt dome.

Mining Company was organized. A shaft was sunk, and it was completed in 1922, after many difficulties in sealing off the surface water (Fig. 4). This shaft, which extends beyond the level of the workings, is approximately 900 feet deep. The shaft is circular in form, is constructed of concrete, and is divided into four compartments. Rooms 40 feet wide and 80 feet high are cut out of the pure salt in the process of mining. A cross section of the salt working is shown in Figure 4. The roof of the salt mass is supported by square pillars of salt 40 feet wide. The salt is blasted down, loaded into cars by electric shovels, hauled to the shaft, and hoisted to the surface by means of an electric hoist. The salt is prepared and packaged at the mine.

Actual salt production was begun in April, 1923, and has continued since that date. During 1932 an evaporation unit was added to the salt mine. Package table salt, bulk rock salt, and several related products are produced by the Jefferson Island Salt Mining Company. Approximately 8,000 cars of salt per year are shipped from the mine. More than 2 million tons of salt have been produced by the Jefferson Island Salt Mining Company from the Jefferson Island dome, as shown in Table I.

TABLE I

SALT PRODUCTION, JEFFERSON ISLAND SALT MINING COMPANY, JEFFERSON ISLAND DOME

	*Tons**		*Tons**
1923	93,391	1930	218,342
1924	112,974	1931	216,787
1925	160,823	1932	191,764
1926	183,949	1933	204,928
1927	217,424	1934	218,181
1928	228,750		
1929	205,479	Total	2,252,792

* State of Louisiana, Department of Conservation, New Orleans, Louisiana

OIL EXPLORATION

In November, 1924, the United Oil and Gas Syndicate began a drilling campaign along the southern edge of Jefferson Island and Lake Peigneur. Five wells were drilled, all deeper than 4,000 feet (Fig. 5). The logs of these wells recorded slight showings of sulphur, gas, and oil, but no cap rock or salt was struck, indicating that on the south side of the dome, the salt dropped off very suddenly.

After drilling these five wells, the company encountered financial difficulties and was reorganized by the directing heads of the old company under the title of the Jefferson Oil and Development Company. This company drilled two deep tests to depths of 4,552 and 5,965 feet, the former on the eastern edge of Lake Peigneur, and the

FIG. 4.—East-west section through Jefferson Island, showing salt dome.

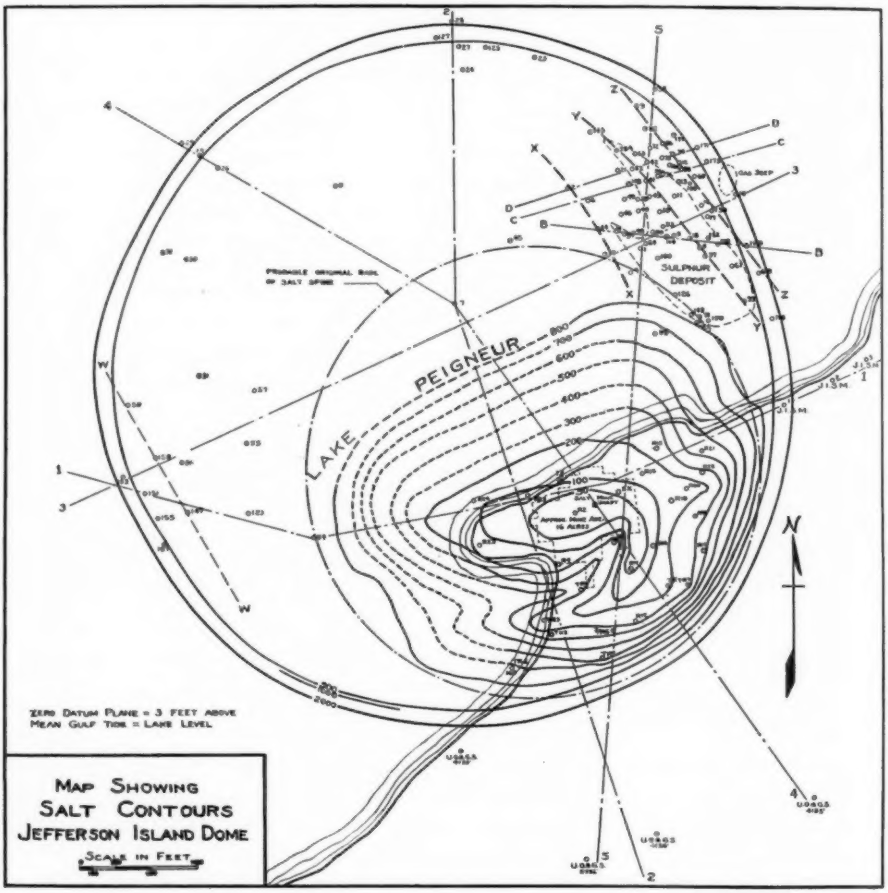

FIG. 5.—Salt contours and well locations, Jefferson Island dome.

latter on the southern edge of the lake. No salt or oil was discovered, although there were slight showings of gas. The company was again reorganized and given the name of the Jefferson Lake Oil Company, Incorporated.

The Jefferson Lake Oil Company's Lake Peigneur No. 10 was drilled to a depth of 2,168 feet. Salt was encountered at 2,057 feet, a total of 111 feet of salt being drilled before the well was abandoned. An oil showing was found in 73 feet of porous limestone, beginning at 1,763 feet. However, an insufficient amount of gas was reported to make a producer.

Oil was reported in well No. 25, which was also a flank well. This well encountered salt at a depth of 1,902 feet.

A gas seep had been reported for years on the eastern side of the dome, and in the lake. This seep was again noticed early in the spring of 1934. An area of about 2 acres just north of well 10 in the lake was in continual agitation (Fig. 5). The gas did not have the characteristic odor of hydrogen sulphide, and apparently was a petroleum gas. One of these large bubbles was ignited, after which it burned for 8 hours before being extinguished by wave action. This gas seep continued for several months, and was still very active when last noticed by the writer.

While salt was being mined in the southern part of the salt mine, an oil and gas seep was encountered in the salt, and caused the abandonment of this part of the mine. Jefferson Island is still a good prospect for flank oil, and it is the intention of the management of the Jefferson Lake Oil Company to drill for this oil at a later date.

SULPHUR EXPLORATION

The discovery of the sulphur came accidentally in a supposedly deep flank test which was located by the Jefferson Lake Oil Company on the advice of a consulting electrical geophysical company. This well was located in Lake Peigneur directly in front of the salt mine. At a depth of about 600 feet limestone was unexpectedly encountered. At a depth of about 650 feet, true cap rock was struck, and at a depth of 660 feet, the bit picked up traces of sulphur and continued deeper with increasing quantities of sulphur until a thickness of 164 feet had been drilled, when anhydrite terminated the sulphur zone. At a depth of 871 feet, pure rock salt was struck. The well was drilled to a depth of 1,136 feet, and abandoned in salt after being drilled through 266 feet of salt. The high purity of the sulphur encountered and the great thickness of the deposit gave all indications of a very rich discovery.

PALEONTOLOGY

Fossils were found in the railroad cut on the north side of the island, and these have been identified by Mansfield and Marshall[6] as genera in the recent fauna. The horizon, as indicated by the imperfect preservation of the fauna, probably is late Pleistocene or early Recent. As these could not have been deposited in their present position, they indicated that the mound was probably formed by a very late Pleistocene or post-Pleistocene uplift.

Very little paleontological work has been done on the strata underlying the lake, and no paleontological records could be obtained for the deep wells on the flanks of Jefferson Island dome.

GEOLOGY

There are two distinct features in the geology of Jefferson Island salt dome: the salt spine and Lake Peigneur.

SALT SPINE

The salt spine rises 850 feet above the main salt stock, projecting through the sediments covering the salt stock, and nearly reaching the elevation of the surrounding plains. It has forced the overlying strata upward, forming the elevation "Jefferson Island," which is approximately 75 feet above the surrounding plains. The salt spine is decidedly circular in form, and is in the shape of a cone.

Salt was encountered at a depth of 104 feet from the surface in the sinking of the salt-mine shaft into the salt spine. Before reaching the salt, the shaft passed through 12 feet of clay, and 2 feet of lignite. Cap rock, which consisted of 18–25 inches of porous limestone, was found on a few of the holes drilled on the salt spine. However, most of the exploration holes showed that about 10 feet of gumbo made direct contact with the salt (Table II).

Solution of salt and consequent subsidence seem to be an important cause of the exceptional topography of Jefferson Island. This topography is in the form of two peninsulas extending from the elevation of Jefferson Island into Lake Peigneur. Figure 2 shows how closely the salt of the salt spine contours conform with the surface topography. The solution of the salt is definitely a cause of the peninsula shown in the left side of Figure 2. On the right side of the figure, the water has begun to dissolve the salt and a peninsula is forming. In future years, as this solution of the salt continues, the two ravines in the salt spine will meet, with the resulting subsidence

[6] Francis Edward Vaughan, "The Five Islands, Louisiana," *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926), p. 360.

forming a definite island in Lake Peigneur. Jefferson Island would then be very similar to the other Five Islands. Figure 5A shows a photograph of these two peninsulas in the lake, together with the subsidence area.

TABLE II

WELLS TO SALT ON SALT SPINE*

(Depths in Feet)

Well No.		*Top of Cap*	*Top of Salt*	*Total Depth*
JLO	4	Broken cap rock	852	859
	54	Broken cap rock	863	859
	98	666	670	671
	152	734	857	863
TR	1	No cap	322	324
	2	No cap	405	408
	3	No cap	269	273
	5	No cap	394	398
	6	No cap	392	393
Shaft	1	—	54	825
R	1	—	40	—
	2	—	174	—
	11	—	49	—
	14	—	165	—
	15	—	210	—
	18	—	230	—
	19	—	162	—
	20	—	170	—
	22	—	254	—
	23	—	190	—
	24	—	89	—
	25	—	122	—
X	1	—	115	—
X	5	—	68	—
X	7	—	207	—
X	8	—	260	2,186

* Lake level taken as datum plane, which is 3 feet above mean gulf tide.

Geologists have believed that the bluff north of the island was formed solely by the wave action of the lake. However, a study of the salt contours over the bluff indicates that the solution of the salt, with the resulting subsidence, has been an important factor in the bluff formation. The writer has noticed fresh evidence of subsidence along the bluff. This bluff as it now exists is shown in Figure 11, between the shaft and well No. 1-X, and also in Figure 7, between the shaft and well No. R-25. The salt spine, as it dissolved, served as a slip-plane for the bed above that was in the process of subsiding, the resulting fault which caused the bluff being just slightly beyond the point where the salt spine begins to dip toward the main salt stock, the fault occurring at this weak point where there is approximately 100 feet of overburden.

FIG. 5A.—View of Jefferson Island, showing 900-foot contour, with salt mine in foreground, and sulphur wells and trestle in background. By courtesy of Fairchild Aerial Surveys, Inc.

LAKE PEIGNEUR

The bed of the lake is composed of silt and soft gumbo, ranging in thickness from 20 to 35 feet. Below this soft gumbo is a layer of hard gumbo, imbedded with small amounts of sand and gravel. This is followed by 150–200 feet of sand and gravel overlying an irregular amount of gumbo, which is immediately above the cap rock.

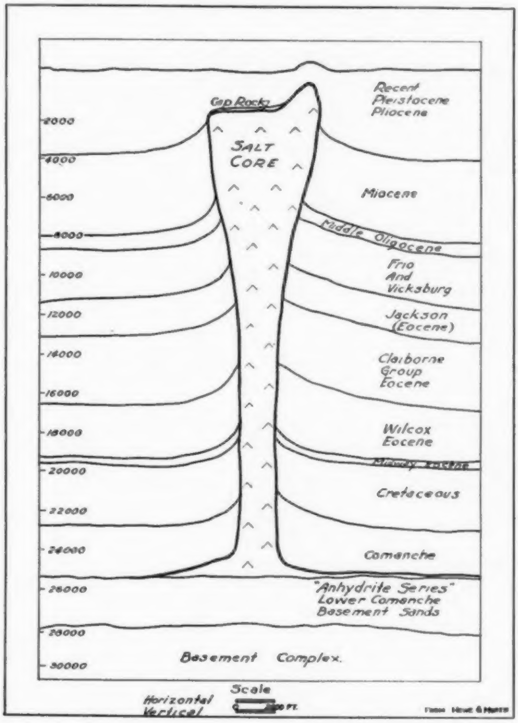

FIG. 6.—Typical Iberia Parish salt dome.

The cap rock is the hard formation overlying the salt, and includes limestone, calcite, and anhydrite, and in some places, small strata of sand and gumbo. This cap rock underlies approximately 400 acres. At its highest point, it is about 580 feet below the surface of the lake, and varies in thickness from 300 feet under the center of the lake to only a few feet at the edges of the dome.

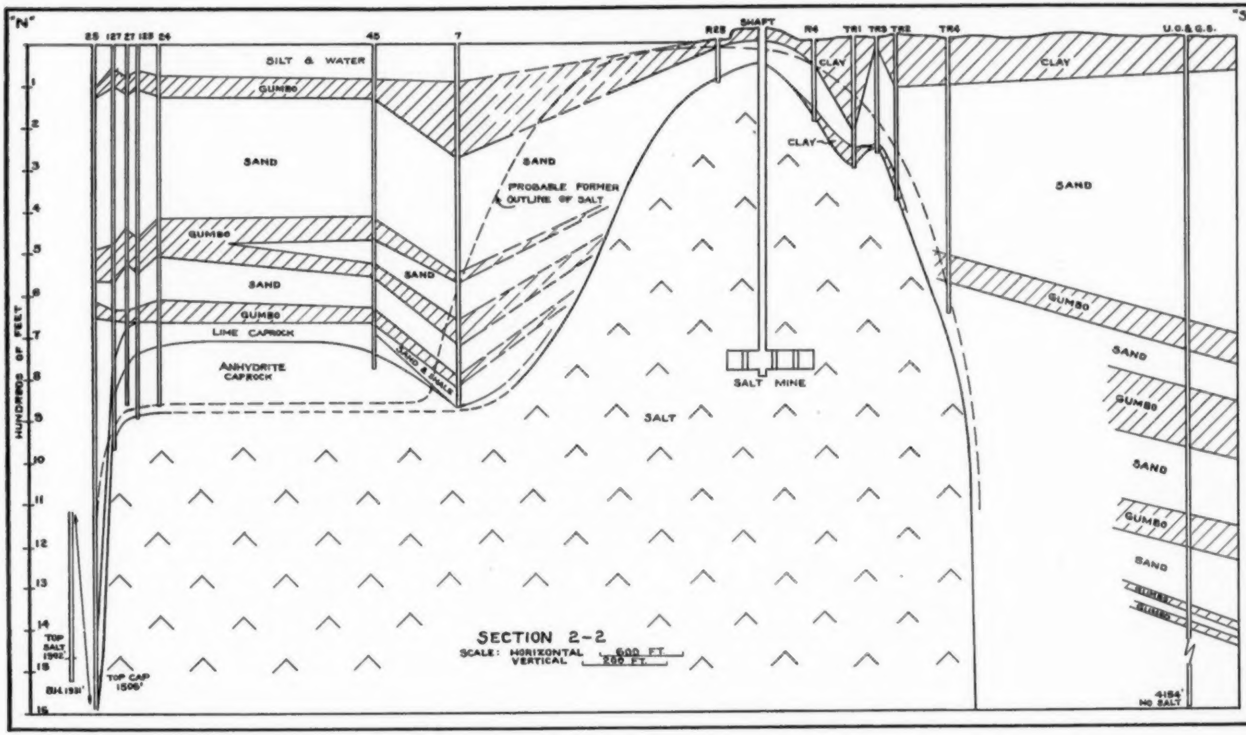

FIG. 7.—North-south section through center of dome.

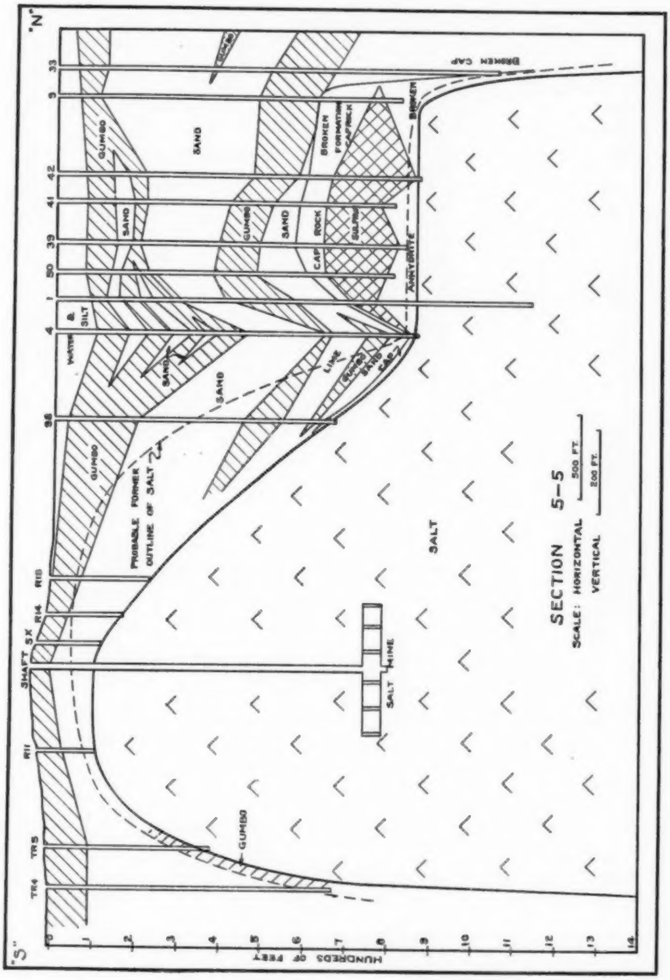

FIG. 8.—North-south section through sulphur deposit.

Subsidence of the cap rock and the sand and gumbo strata over the cap rock caused by solution of the salt is the outstanding characteristic of the Jefferson Island dome. The greatest amount of this subsidence has taken place in a semi-circular area adjacent to the salt spine. This subsidence is shown in Figure 7 at well No. 7; in Figure 8 at wells No. 98 and 4; and in Figure 4 at well No. 54. It will be noted from a study of these figures that the upper sand and gumbo beds above the cap rock have subsided in some places into the area of the cap rock. The watery silt and the soft gumbo so common to the bottom of Lake Peigneur have run into this subsidence area, tending to level the lake bottom, and forming the thick surface bed of gumbo over the subsidence area.

The greatest amount of subsidence has taken place on the north portion of the salt spine at well No. 7. Here, the surface water apparently has been able to make more active contact with the salt, dissolving this salt at a higher rate, and giving the flat appearance to the salt contours as shown in Figure 5. So much solution of the cap-rock-free salt spine has taken place at this point that there is very little cap rock in the area, the cap rock being replaced by sand and gumbo. The sand and gumbo beds have subsided more than 200 feet in this area, as is shown in Figure 8 at well No. 4.

On the east end of the salt spine at well No. 71, there has not been as much solution of the salt spine, as the cap rock at this point is in a very solid condition, and showed very little evidence of subsidence. The sand and gumbo beds above the cap rock have subsided very little.

On the west side of the salt spine, as shown in Figure 4 at well No. 54, there has been some solution of the salt, as the cap rock in this well was much broken and mixed with gravel and gumbo. The sand and gravel beds above the cap rock also show evidence of subsidence.

Evidence shows that the salt spine, together with its base, was probably circular in shape before solution took place. A dot-dash circle has been drawn in Figure 5 which shows the probable limits of the salt spine before solution took place. From a study of the sections in Figures 4, 7, 8, and 11, it will be seen that the greatest subsidence has taken place within the area of the dot-dash circle, giving evidence that the base of the salt spine probably extended to this dot-dash circle before solution took place.

The writer has shown on several sections of the salt spine the probable original outline before solution took place (Figs. 4, 7, and 8).

The purity of the salt both from the spine and from under Lake

Peigneur has been shown by test to be exceptionally high. The salt actually has less than 1 per cent of anhydrite. Because of the small amount of anhydrite, no cap rock was formed where solution took place.

TABLE III

WELLS TO SALT ON TOP OF DOME EXCLUSIVE OF SOUTHWESTERN PART OF DOME*

(Depths in Feet)

Well No.	*Top of Cap*	*Top of Salt*	*Total Depth*
JLO 1	666	871	1,136
11	582	860 (?)	861
42	598	868	871
44	525	908	909
47	751	869	872
89	675	869	870
91	579	871	872
114	710	869	873
120	770	871	872
121	785	874	875
124	781	869	874
126	786	868	875
128	746	868	875
139	852	868	873
140	858	868	872
149	725	867	875
150	771	867	872
154	808	869	870
156	778	868	875
159	702	868	871
160	752	865	870
169	819	869	878
176	569	874	875
183	690	867	890
186	781	871	878

* Lake level taken as datum plane, which is 3 feet above mean gulf tide.

The salt table is exceptionally flat on this dome, as most of the wells that went to salt encountered the material at approximately 871 feet (Table III). It will be noted that several wells in Table III encountered salt from 871 to 874 feet, which wells are not shown in the sections of the dome. These wells could not be shown in the sections, as most of them were drilled after subsidence from sulphur mining. However, these wells definitely show that the salt plane is at 871 feet, as shown in the sections. The exceptions to this are the wells

TABLE IV

WELLS TO SALT ON TOP OF SOUTHWESTERN PART OF DOME*

(Depths in Feet)

Well No.	*Top of Cap*	*Top of Salt*	*Total Depth*
JLO 147	719	922	923
151	731	921	929
155	702	921	922

* Lake level taken as datum plane, which is 3 feet above mean gulf tide.

TABLE V

WELLS TO SALT ON FLANKS OF DOME*

(Depths in Feet)

Well No.	*Top of Cap*	*Top of Salt*	*Total Depth*
JLO 10	1,749	2,057	2,168
23	730	878	880
25	1,506	1,902	1,931
28	691	912	914
69	792	985	985
123	841	985	988
125	715	980	989
127	855	955	960
143	770	875	878
148	744	873	877
161	716	874	878
164	742	936	937
166	690	906	910
168	734	946	950
171	818	981	1,020
174	721	937	982
175	779	970	975
180	979	1,016	1,019
185	725	908	911
Salt Mine No. 1	1,017	1,151	1,186

* Lake level taken as datum plane, which is 3 feet above mean gulf tide.

TABLE VI

IMPORTANT WELLS THAT DID NOT ENCOUNTER SALT*

(Depths in Feet)

Well No.	*Top of Cap*	*Total Depth*
JLO 2	635	865
7	864	874
8	631	772
9	615	819
24	685	865
26	666	855
27	670	867
29	No cap	1,019
30	610	840
31	812	880
32	615	845
33	968	1,039
45	646	757
55	550	811
57	600	767
58	549	831
118	No cap	939
129	773	912
153	1,059	1,421
157	798	929
158	800	900
173	No cap	910
184	No cap	1,339
Salt Mine No. 2	—	2,916
R 12	—	298
R 17	—	321
R 21	—	400
TR 4	—	684
TR 6	—	606

* Lake level taken as datum plane, which is 3 feet above mean gulf tide.

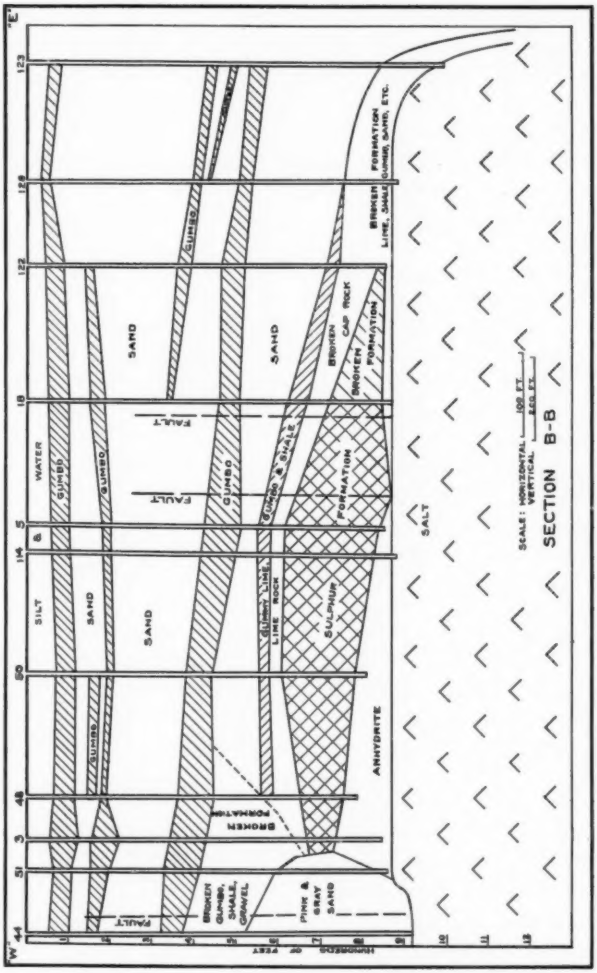

Fig. 9.—Section through south end of sulphur deposit.

on the southwest edge of the dome, which found salt at approximately 921 feet. These wells seem to be along a fault.

There has been no evidence of overhang on the flank of this dome, as the drill has as yet not penetrated the salt.

There is evidence of three faults in the cap rock on the eastern part of the dome. These faults extend northwest and southeast, and are shown in Figure 5 by the dotted lines *XX*, *YY*, and *ZZ*. Indications are that the cap rock has slid off the salt on this side of the dome, causing these tangential faults. The faults have entirely different characteristics, and apparently have a bearing on the sulphur deposits.

Fault *XX* is shown in section in Figure 9 at well No. 44; also in Figure 10 at wells No. 44 and No. 35. Well No. 44 drilled through 350 feet of pink and gray sand, and did not encounter salt above the depth of 909 feet. The drilling of several wells has shown that the normal salt table in the vicinity of this well is at a depth of approximately 871 feet. This pink and gray sand was also encountered in wells No. 2 and No. 4, yet not to the same extent as in the two previously mentioned wells. This sand was not a water sand, as it was packed tight, and served as a barrier to the passage of any water. This "pink and gray sand," as the drillers call it, is fine, uncemented anhydrite. It is to be noted in Figure 10 that the cap rock, together with the gumbo and sand beds, has been pushed upward by the wedge of anhydrite sand, giving indications that the sand came from a lower point. The only possible supply would be residual, uncemented anhydrite; the anhydrite was freed from the salt as it went into solution in the porous space between the salt and the anhydrite cap rock common on this dome. This uncemented anhydrite, due to the pressure of the overlying cap rock and sediments, broke through along this line of tangential faulting in the cap rock and displaced the strata above the cap rock.

There is some question as to *YY* being a fault. However, it is so designated because it is the lowest part of the valley-shaped basin in which the sulphur is deposited. Along this line there is a break in the anhydrite, the sulphur making direct contact with the salt and the massive anhydrite rising steeply on either side of the line, especially on the sides of the north end (Fig. 13).

Along the fault *YY*, the sulphur deposit is placed in a depression or cavity which is much like the shape of a valley, as is shown by the dotted lines in Figure 5. The sulphur deposit is narrow and thin and at a high elevation at the headwaters of the valley, fairly wide and thick at the middle part of the valley, and flatter and wider and at a greater depth in the flat plains beyond the valley.

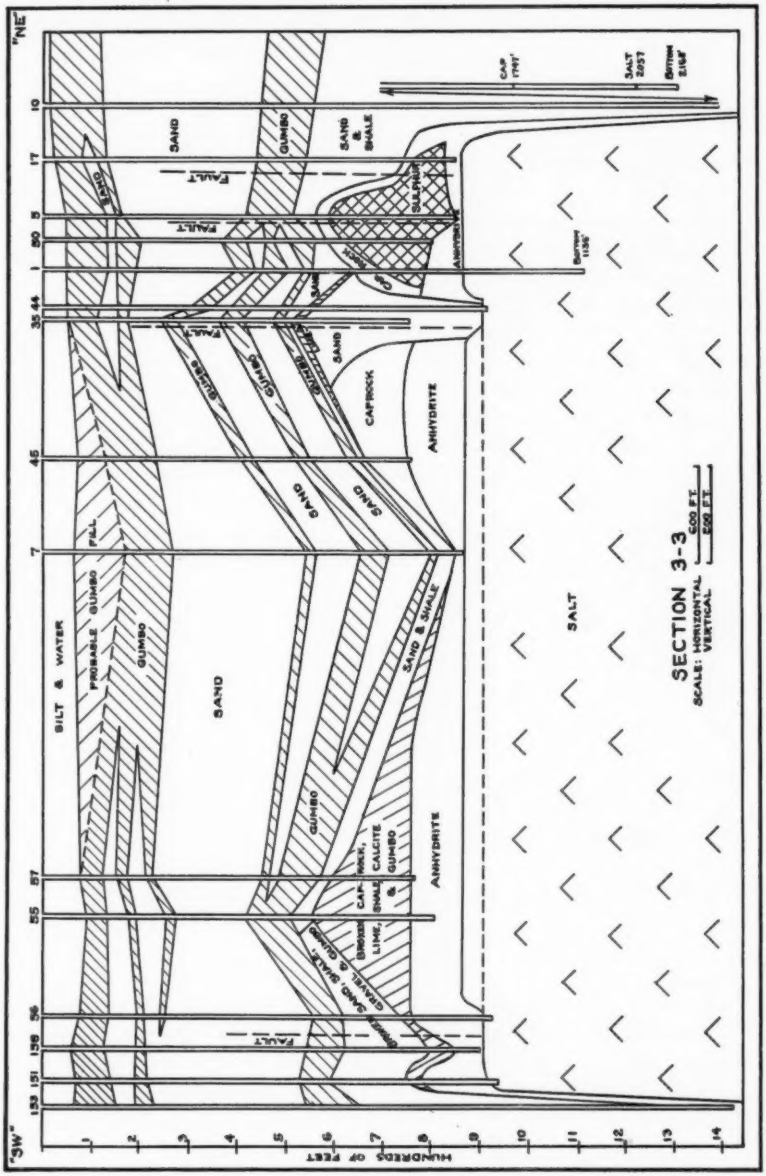

FIG. 10.—Northeast-southwest section through center of dome.

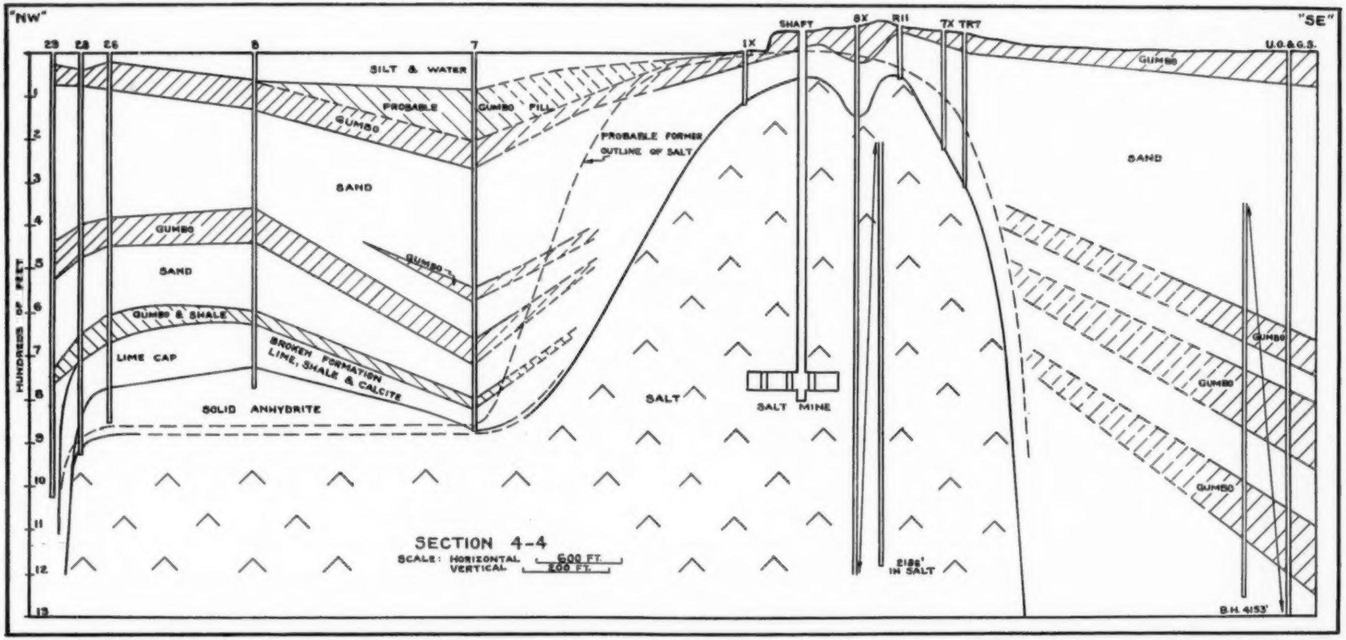

FIG. 11.—Northwest-southeast section through Jefferson Island dome.

Fault *ZZ* is shown in Figure 5, and it also can be seen in several of the sections through the sulphur formation, especially Figure 12 at well 88. Very little sulphur was found beyond this fault on the flanks of the dome. What sulphur was found, together with the overlying cap rock, was in a much broken condition and mixed with gumbo and sand. The importance of this fault is realized when it is understood that in sulphur production it is essential that the underground sulphur strata be pressure-tight to maintain the pressure necessary to melt the sulphur (as essential as that a boiler must be free of holes and leaks to maintain its pressure). In the area west of this fault, pressure was maintained—in fact, slight drops in the volume of the water bled from the dome would immediately raise the pressure in this area; however, in the area east of the fault, pressure could not be maintained, the area taking all the water that could be forced into it.

The sulphur is deposited between these two tangential faults, the impervious anhydrite fault sealing the pressure on one side, and the broken compact formation caused by the fault sealing the pressure on the other side and tending to confine the migrating hot waters necessary for sulphur formation to a long narrow strip. At the Boling dome, the main deposit of sulphur is confined, not by a fault as at Jefferson Island, but by what is known as a "gypsum backbone," a thick bed of gypsum which extends about 2 miles across the dome. However, there are minor faults on this dome which serve as pockets for the accumulation of sulphur, one of these faults being similar to the anhydrite fault on Jefferson Island.

The cap rock has also slipped over the edge of the salt stock on the southwest part of the dome, forming the fault *WW* in Figure 5. This fault is further shown in Figure 10 at well No. 158. There were some indications of sulphur in the southwestern part of the dome in the vicinity of well No. 129, though, as yet, not enough sulphur has been found to make a commercial operation.

The faults on the Jefferson Island dome are not characteristic of faults in hard formation, as the fault is not a clean break, especially in the sand and gumbo beds above the cap rock, which has a tendency to subside over the fault rather than to break. As the numerous sections show, the gumbo tends to stretch, thinning over the fault, and the sand and shale beds tend to flow into the fault. In this way, sand and shale beds thicken at the point of the fault, and thin on the sides of the fault.

MINERALS IN CAP ROCK

The cap rock in the sulphur area in vertical section is composed of three zones (Figs. 12 and 13), as follows: a thin layer of limestone,[7]

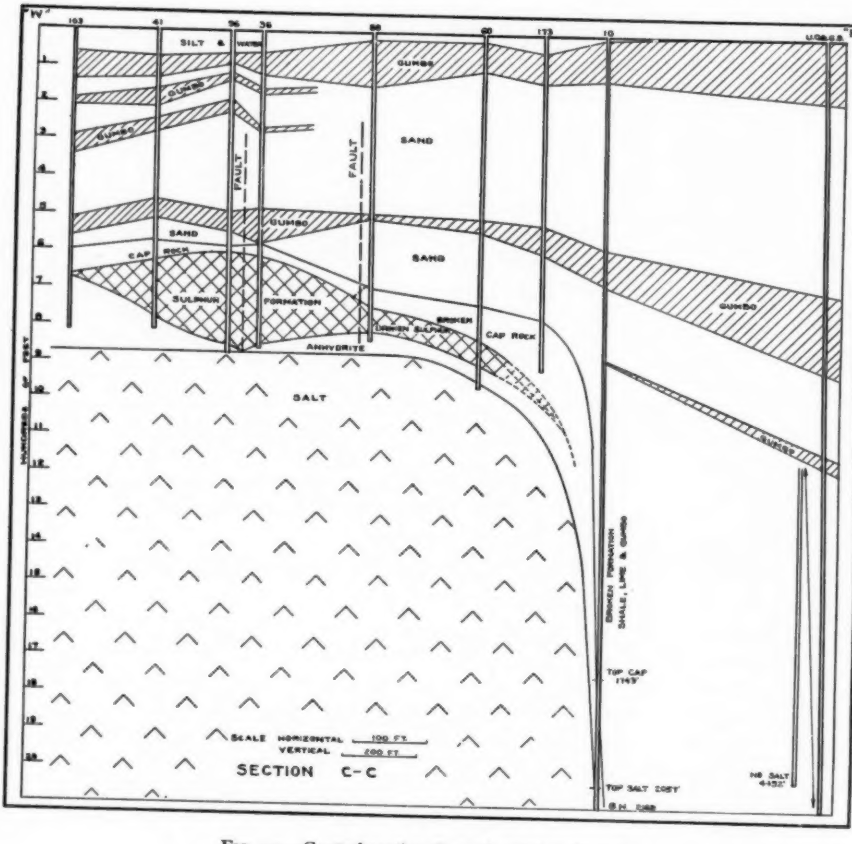

FIG. 12.—Central section through sulphur deposit.

which contains some calcite; an intermediate zone of limestone, calcite, and sulphur; and an anhydrite zone, which is directly over the salt and in contact with it. One or two of these zones may be entirely missing in places, as in some places the drill passes directly from the gumbo into the sulphur formation. In other places, the drill may pass from the sulphur formation directly into the salt. Away from the sulphur area, in places, only the anhydrite is present. At faults, as on Figure 5, a dike of uncemented anhydrite sand may occur.

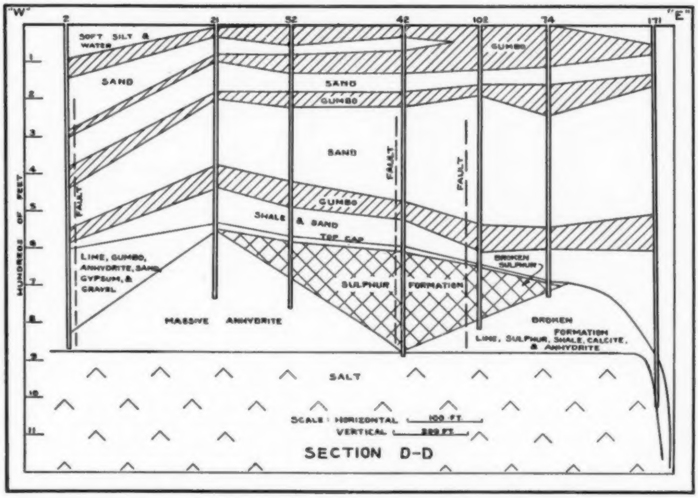

FIG. 13.—Section through north end of sulphur deposit.

The limestone of the upper zone is broken and unconsolidated, in places mixed with gumbo, sand, and shale. In most places, it is medium-grained limestone, dark gray in color, irregularly banded, brecciated, and re-cemented with white calcite.

The sulphur zone varies in thickness from a few feet to 300 feet. This zone contains some limestone similar to that in the upper zone, together with calcite and a non-uniform richness of sulphur. Small amounts of sand, quartz, chert, barite, pyrite, gumbo, selinite, and shale are found in this zone.

In most places, the sulphur in the sulphur zone is in direct proportion to the limestone and calcite, and in inverse proportion to the

[7] The limerock of the cap of the Gulf Coast salt domes is not a limestone in the strict sense of the term, and many geologists object to the use of "limestone" for that limerock—Editors.

anhydrite. As the sulphur zone merges into the anhydrite zone, the anhydrite becomes more and more massive, the percentage of calcite and limestone decreases, and finally, there are only the most minute particles of sulphur in solid anhydrite.

The sulphur itself is irregularly distributed. It is found in crystals varying greatly in size, also, in thin layers banded with limestone and calcite, and in other places, it is found as large masses of crystalline sulphur extending upward through the strata. In places it is in the shape of stalactites and in the openings of crevices made by circulating waters. Also, the sulphur forms in thin sheets in faults or cracks in the rock-like formation. The sulphur is commonly in the opaque form: a soft, powdery, pale yellow type. In the crystalline form, the crystals are green-to-amber to bright yellow, the color apparently not affecting the purity.

The formations and sulphur content in the sulphur zone are irregular, no two wells being of the same character or content. At one place excellent sulphur was found in four wells, each forming the corners of a square, though the center of the square was practically barren of sulphur.

Oil is found in some places in the sulphur zone, passing from the upper limerock into the lower sulphur zone through faults and through porous formation, this faulting and porosity in many places being caused by subsidence. Along fault *ZZ*, the sulphur zone is unconsolidated, there being a broken mixture of limerock, calcite, sulphur, anhydrite, and sand, all cemented together with bitumen.

The anhydrite zone is directly under the sulphur zone. This zone is composed almost wholly of anhydrite, and constitutes 95 per cent of the mass between the sulphur and the salt. The texture of the anhydrite is crystalline, giving it a sugary appearance. It ranges in color from pure white to black, and in places is difficult to distinguish from the limestone and calcite. This anhydrite zone varies in thickness from a few feet to 200 feet, and is irregularly distributed throughout the dome. Layers of unaltered anyhydrite are found in the sulphur zone in places.

A condensed description of the three zones from the cores of well No. 36 was furnished by R. Dana Russell of Louisiana State University and is shown in the Appendix. Russell examined these cores with a hand lens, the microscope being used only to identify barite. This well was the first to produce sulphur on Jefferson Island dome.

The porous sulphur area originally was filled with warm saturated brine about 90°F. in temperature, in which is dissolved many of the

minerals of the sulphur zone, together with the sulphides, hydrogen sulphide gas, and methane gas. The minerals in the formation water, especially calcite, anhydrite, and the different forms of sulphur compounds, go into solution, and are reprecipitated in other portions of the sulphur formation, this process going on continuously. This is the cause of the calcite cementation of the calcareous breccia, also the cause of the sulphur being deposited in the cracks and crevices.

The waters that flooded the porous sulphur area at Jefferson Island were decidedly less saturated with salt than is characteristic of most sulphur-mining formation waters. At the beginning of operations, Jefferson Island had only 180 grains of sodium chloride per gallon, in contrast to 3,670 grains per gallon on the Boling dome, and 3,776 grains per gallon on the Big Hill dome.

GEOPHYSICS

The first geophysical survey on the Jefferson Island dome was an electrical survey made by the Elbof interests of Germany. This survey accidentally led to the discovery of sulphur in the Jefferson Lake Oil Company's well Lake Peigneur No. 1. After drilling this well, the company decided to explore purposely for sulphur.

The McCollum Exploration Company, of Houston, Texas, was hired to make the seismograph survey of the dome. Their survey, May 8, 1929, showed that the dome was approximately the same size and shape as the lake, and further showed that the dome lay directly under the lake. Piling was then driven into the bed of the lake, tramways were made, and an extensive drilling campaign was organized. Nine wells were drilled, all of which had rich and thick strata of sulphur. In the meantime, a torsion-balance survey was made by Donald C. Barton to determine the approximate extent of considerable thickness of cap rock. This survey fairly well verified the conclusions of the former survey. However, well No. 10, which was indicated to be on the cap rock by both of these surveys, was drilled to a depth of 2,168 feet, where salt was found. This well showed that the delineations of the sides of the dome by the former surveys were inaccurate, and the McCollum Exploration Company again surveyed the island. Their report of January 2, 1931, showed the dome as being slightly smaller than indicated by the original surveys, but approximately the same shape and well confined within the shores of the lake.

Drilling up to the present time, 198 holes, has shown that this survey has been very accurate.

PROBABLE ORIGIN OF SALT STOCK AND SPINE

There is much evidence at Jefferson Island to support the theory that the salt spine was formed at great depths and then rose to the surface *en masse* with the main salt stock.[8]

This could have occurred as follows. A small portion of the salt protruded through a fracture in the strata overlying the salt beds, which are at great depths. On passing through this fracture, the salt spine assumes a pointed shape and, as a result, clears itself of cap rock on further rising. On reaching a certain elevation above the main salt bed, which in this case would have been approximately 850 feet, a large portion of the cap rock overlying the salt bed breaks, allowing the main flat portion of the salt stock to rise, carrying the cap rock with it.

As the salt spine passes through the fracture and begins to penetrate the overlying strata, it still maintains its pointed shape, and assumes more and more a circular cross section, the form of easiest flow and least wall friction, and the form the salt spine would be expected to assume in penetrating the numerous strata in rising from great depths. It also clears itself of the remaining cap rock, as is shown by the wells drilled to the salt spine, which wells were free of cap rock.

The main salt stock does not assume a pointed shape, as it has the heavy cap rock over the salt table, which serves as a protective shield to maintain its flat surface. The cap rock is broken and crushed as a result of the immense forces involved by this flat surface penetrating the overlying sediments. Tangential faults, as shown in Figure 5, would naturally occur. On rising, the main salt stock would also assume a circular shape.

As the salt on the flanks of the salt stock was dissolved by the fresh water of the sands penetrated, the cap rock would tend to break off, forming a broken cap rock on the flanks of the salt stock, which cap rock would be further added to by the impurities from the salt dissolved. This flank cap rock is very common at Jefferson Island. As shown in Figure 4, J. I. S. M. No. 1, and in Figure 8, well T. R. No. 4, this cap rock has formed only at depths greater than 800 feet, the approximate depth of the main cap rock.

ORIGIN OF CAP ROCK

The main hypotheses of origin of the anhydrite cap of the Gulf Coast salt domes are two.[9]

[8] Levi S. Brown, "Age of Gulf Border Salt Deposits," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 10 (October, 1934), p. 1283.

1. *Sedimentary origin.*—The anhydrite was an original sedimentary deposit over the salt while the salt was at great depth, and was pushed up on top of the salt stock during its rise into the overlying strata, and while this operation was proceeding, the anhydrite was brecciated, later being re-cemented to form the present anhydrite cap rock.

2. *Residual origin.*—The anhydrite was formed close to the surface by the salt going into solution, leaving the grains of anhydrite on top of the salt stock, the process of cementation forming the anhydrite cap rock.

The data at Jefferson Island indicates that at least a portion of the cap rock immediately adjacent to the salt is of residual origin. When the salt is dissolved by migrating waters, the anhydrite, which does not go into solution, remains to add to the overlying cap rock. Because of the high purity (less than 1 per cent anhydrite) of the salt at the present salt contours, this action now adds very little anhydrite to the present cap rock of Jefferson Island. Nevertheless, it no doubt was a factor in the formation of the uncemented anhydrite sand fault mentioned previously in this paper.

With reference to the solution of the salt by migrating waters, some interesting facts were developed by a study of the 20 holes that were drilled to salt on top of the eastern half of the salt table. All of these holes, with the exception of well 44, which was in a fault, encountered salt from 871 to 874 feet, and showed the salt table to be very flat. In most places, the slight differences in the elevations of the salt table were due to the change in the elevation of water on the lake, with a consequent variation in the elevation of the floating drilling barge.

A 2-foot cavity at the contact of the salt and anhydrite rather commonly is encountered in wells. This cavity, which was filled with salt water, takes all the drilling mud that can be pumped into it. From all appearances, it is very extensive in character, covering the whole dome. The cavity was found even in the southwestern quadrant of the dome, where, in a small area, the salt plane was encountered at a depth of 921–922 feet. Where cores of salt were taken in these cavities, 6 inches of the top of the salt was of a mushy, wet nature. The writer has noticed that this condition exists at the Boling dome in wells that were drilled to salt.

No doubt a series of arches and columns of salt exists tending to

[9] For discussion of these hypotheses, see Marcus I. Goldman, "Origin of the Anhydrite Caprock of American Salt Domes," *U. S. Geol. Survey Prof. Paper 175-D* (1933).

support the overlying cap rock. The few wells that did not contact the cavity probably were drilled into one of the supports. The waters circulating in these caverns are gradually dissolving the salt and cutting out these arches. The heavy, saturated salt waters settle to the bottom of the cavity where, although making contact with the salt, they can dissolve no further salt because of their super-saturation. The lighter, unsaturated waters are then at the top of the cavity, where they act as a solvent for any higher elevations of salt, the process gradually levelling the mass, and tending to create a flat salt table. The action is very slow, because of the nature of the process which does not allow the waters to migrate at a high rate. Since the cavity extends to the circumference of the dome, the saturated waters are able to make contact with the fresh-water sands. The pollution of these fresh-water sands is the cause of the high salt-water content characteristic of certain fresh-water sand beds near salt domes. The gradual subsidence tends to break any flank cap-rock seal at the circumference of the dome, and thereby insure circulation of the saturated water. This is verified by the broken cap-rock formation on the edges of salt domes—a condition especially characteristic of the Jefferson Island dome.

All domes do not have this space between the salt and the cap rock. On the domes which do have this space, there is no question that a portion of the cap rock is of residual origin. Those domes which do not have this space are perhaps entirely of sedimentary origin.

That this solution and resulting subsidence are actually occurring at Jefferson Island is shown in Figures 11 and 12, and in other sections of this dome. In Figure 12, it may be seen that the gumbo bed has gradually subsided over the cap rock in the lake, as compared with no subsidence, as shown by the well on the shore of the lake. The second bed of gumbo that was thinned due to the uplift and consequently must have been domed in shape and at a much higher elevation at some previous time, has assumed a flat shape, and is even lowered at well No. 103.

As the salt is dissolved, there is a gradual subsidence causing the basin which formed Lake Peigneur. All of the sections of the dome show that there was no definite faulting of the overlying strata at the periphery of the salt stock, but that the sand and gumbo beds tended to stretch and thin over the subsidence area and the area adjacent to it. This is one reason for the area of Lake Peigneur being much larger than the area of the salt stock (Fig. 3).

Where subsidence was obtained in sulphur mining, the writer noticed that the area would immediately tend to fill up with silt and

soft gumbo, due to the watery nature of the top silt strata of the lake bottom, and the very muddy nature of the flood waters flowing into the lake. This situation also occurred where natural subsidence took place, as indicated by the thick strata of gumbo and silt in the bottom of the lake around well No. 7.

All wells drilled on the flanks of the Jefferson Island dome close to the salt core encountered cap rock. A study of logs show that this cap rock was of varying thickness dependent on the angle of contact; however, on studying the sections (Figs. 4, 7, 12, et cetera), it is found that there is a blanket of cap rock covering the flanks that varies in thickness from 10 to 30 feet. It was difficult for the drillers to tell definitely when this cap rock was encountered, as the cap rock was in a broken and unconsolidated condition.

The broken, unconsolidated condition so characteristic of the formation of the flanks of this dome could, then, be caused by the salt going into solution on the flanks of the dome. The resulting subsidence would not be the same as on the top of the dome, namely, the vertical drop of a large cap-rock table, but would be a combination of vertical subsidence and a horizontal radial movement toward the center of an immense annular ring of cap rock. This ring would tend to be further crushed by the immense load due to the thickness of the cap-rock material it tends to support. This movement would not be characteristic of a dome which has a gently sloping flank, say of 45° or less. This ring would include material broken off of the main cap rock.

The numerous cross sections of the dome disclosed a dip in the top gumbo strata immediately over the flank of the salt stock. Since this characteristic developed in many of the sections and is the result of drilling logs made by a number of different drillers, it would appear that it is more than a coincidence. This dip is shown in Figure 7 at well No. 25; Figure 10 at well No. 151; Figure 11, well No. 28; Figure 12, well No. 173; and Figure 13, well No. 171.

In the subsidence of unconsolidated sediments, the horizontal width of the slumping must be equal to the depth of the cause of the slumping, and the slumping takes place in a cone space. Since the cause of the slumping in flank solution is along a vertical plane which may extend to great depths, the horizontal width of the basin at the surface caused by this vertical solution would be fairly extensive, and as a consequence, the basin would not be very deep or pronounced. However, where the combination of both solution of the salt of the flank and solution of the salt on the top of the salt table took place as would occur on the rim of the Jefferson Island salt dome, the basin would be of smaller horizontal distance and greater thick-

ness in depth, and would be superimposed on the more extensive basin caused by the deep flank solution.

It will be noted in the aforementioned figures that where there has been enough drilling to show the width of the basin, it is approximately equal to the depth to the top of the rim of the salt stock. A possible explanation of the circumferential basin or "rim syncline" is the combination of flank solution and solution of the top of the salt table at the rim of the salt stock.

In this discussion covering the origin of the salt stock, salt spine, and cap rock, the writer has taken the voluminous drilling data of Jefferson Island, and by developing it, has tried to determine whether it will furnish evidence to prove any of the many theories as to the formation of the Jefferson Island dome. Some of these data correlate very closely with individual theories. However, what is true of the Jefferson Island dome may not be true of another dome, as the salt stocks are entirely different in shape and content.

For example, a salt stock with a top that slopes at 45° would not be expected to carry cap rock from the mother salt strata to the surface, as this type of dome would clear itself of all cap rock long before reaching the upper strata. However, if the salt stock were to be very impure, a cap rock may develop after the salt stock has reached the surface, the thickness of the cap rock depending on the amount of solution, and the impurities in the salt.

ORIGIN OF SULPHUR

Oil has been produced on many salt domes, but on only six of the hundred or more in the Gulf Coast has sulphur been successfully produced. It is interesting, therefore, to consider just what may be the possible causes of the formation of the sulphur in these special domes. There are two theories advanced, the bacteria theory, and the carbonaceous theory. For an interesting discussion of these two theories, see Wolff.[10]

EXPLORATION OF SULPHUR

Several test wells had found excellent indications of sulphur by May, 1931. Construction of a sulphur-mining plant was begun by the Jefferson Lake Oil Company during October, 1931, and the first sulphur was successfully produced on October 20, 1932.

The novel necessity of mining sulphur in the middle of a lake involves several new engineering problems. As the power plant is situated on the shore of the lake, approximately one mile from the

[10] Albert S. Wolff, "Big Hill Salt Dome, Matagorda County, Texas," *Geology of Salt Dome Oil Fields* (Amer. Assoc. Petrol. Geol., 1926).

center of mining operations, a trestle had to be built from the power plant to the point of mining (Fig. 5A). Creosoted piling and timbers were used for the construction of this trestle, which carries five pipe lines and a 3-foot wide board walk. The lines terminate at the sulphur station on the western side of the lake. At this station, booster pumps are located for forcing water down into the wells. Here also is located the steam-jacketed collecting sump of 40 tons capacity used to collect sulphur from the wells. Steam-jacketed centrifugal pumps transfer the liquid sulphur from the sump to the storage vats, which are on the shore of the lake near the railroad terminal. The sulphur solidifies in these vats. It is then blasted down and loaded into cars by means of locomotive cranes. These vats are approximately 160 feet wide, 500 feet long, and 40 feet high.

MINING OPERATIONS

The success of the Frasch process depends on keeping the underground strata of the dome at sufficient temperature to melt sulphur. This necessitates that the strata must also be pressure-proof, as sufficient pressure must be maintained to keep the water in the formation at the melting point of sulphur.

The sulphur as it is found in the ordinary dome is a yellow orthorhombic crystalline type at a temperature of 90°F., and with a specific gravity of about 2.06. The sulphur melts at about 239°F. and remains in a liquid form until a temperature of 340°F. is reached, when it assumes a molasses-like, gummy character, and can not be readily handled. For this reason, the sulphur must not be heated above 340°F. if a satisfactory removal from the wells is to be obtained.

The superheated mine water (water that enters the formation to melt the sulphur) is not heated in a boiler, but in a special type of direct-contact heater, steam from the boiler mixing with water in this heater. It is found that the temperature of the water as it leaves the heater approximately equals the temperature corresponding with the pressure of the steam entering the heater. Steam varying from 85-pound to 100-pound gauge is generally used, giving a temperature of steam varying from 320°F. to 340°F.

Under average conditions, about 4 pounds of water per pound of steam is used in this heater, making a total of 5 pounds of superheated water coming from the heater.

However, to maintain the water at the temperature mentioned, the water must be kept under pressure; the pressure required being equal to or greater than the original pressure of the steam which heated the water. This pressure is furnished by a booster pump which

takes the water as it leaves the heater, raises its pressure to 300 pounds gauge, and forces it to the point of sulphur-mining operations, where it may again be boosted in pressure and forced down into the well, after which it passes into the sulphur formation.

Experience has shown that it usually takes 2,000–5,000 gallons of water per ton of sulphur mined by the present Frasch process. On this basis, the amount of water used per 24 hours may be several million gallons. This water must be treated so as to remove all scale-forming materials; otherwise, the heaters, pumps, lines to wells, and the wells themselves will plug up with scale, making necessary a very expensive cleaning process.

The hot mine water (water that enters the sulphur formation to melt the sulphur) dilutes with the cooler water of the formation, thereby losing much of its heat. This is especially true of the water as it flows away from the bottom of the well to the outer formations, which formations are beyond the zone of heat application. For this reason, to get the best efficiency, it is necessary to heat the mine water well above the melting point of sulphur. The melting point of sulphur is 240°F., whereas the water usually is heated to 330°F. In fact, the losses are so great that the overall Frasch process thermal efficiency is only 1–5 per cent.

The mine water, on being diluted with the natural water of the formation, absorbs calcium sulphate, carbonate, and chloride salts, and other minerals dissolved in this natural formation water. The mine water also dissolves certain of these salts from the formation. These salts saturate the bleed-water (the excess water drawn from the mine operations for the purpose of keeping the pressure of the sulphur formation from rising to an excessive figure) and when this water is drawn from the formation, a very difficult disposal problem exists, as the water is poisonous and pollutes any stream or body of water that it is turned into. For this reason, it is necessary to treat this water before disposing of it. This treatment, due to the large volume, involves a very expensive investment, together with a large operating cost.

As the hot mine water leaves the sulphur well and passes into the sulphur formation, it immediately rises, as it is a pure water and has a gravity of 0.90 at a temperature of 330°F. and is much lighter than the natural water, which is saturated with salts and is cooler. In some cases, a very difficult mining problem exists because of this condition, as the water rises suddenly to the top of the formation and does not melt the sulphur in the lower strata of the sulphur formation.

Again, the cooler, heavier, saturated water, because of its greater

head, drops into the well, cooling the well below the point of operation.

The sulphur formation must be pressure-proof, and, in all cases, must hold a pressure corresponding to a temperature above the melting point of sulphur. If the formation could not hold the pressure, the hot water in the formation would flash into steam at the lower pressures, creating a temperature that would not melt the sulphur. While a pressure of 35 pounds would be satisfactory to melt the sulphur, because of inefficiencies it has been found necessary to use 85–100 pounds pressure.

FIG. 14.—Drilling barge of Jefferson Lake Oil Company, Inc.

Since the wells used for the mining of sulphur are very similar to oil wells, an oil-well rotary rig is used for drilling these wells. In the first operations on Lake Peigneur, this rig was installed on top of piling, but this was found to be very expensive, so a drilling rig was developed which could be placed on top of a barge and floated from well to well. This barge is of steel construction, and is permanently equipped with a complete set of drilling machinery (Fig. 14). All machinery on the barge is operated by electricity, which is supplied to the barge by a submarine cable. The barge is held in position by means of four 8-inch pipes placed on its corners, which pipes pass through the barge and into the lake bottom. The barge is maintained

level by a very accurate distribution of the different pieces of drilling machinery. Since the level of the lake rises as much as a foot in a 10-hour period, a telescopic joint was devised to take care of this change in elevation in connecting to the casing of the well. Whereas it takes 3 or 4 days to move the average drilling rig, this rig has been moved from one well to another in as short a time as 12 minutes.

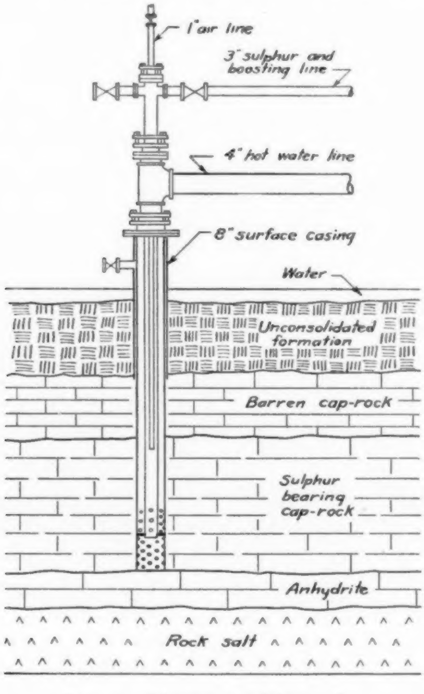

FIG. 15.—Diagram of sulphur well.

In drilling a sulphur well with this barge, a surface casing is first set to shut off the lake water and silt. Then a 10-inch hole is sunk rapidly to cap rock, a distance of 600 feet. An 8-inch casing is set in the hole and cemented. After the cement has set, the hole is drilled and cored to the bottom of the sulphur-bearing formation. The well is then equipped for sulphur mining, which equipment consists of a 6-inch, a 3-inch, and a 1-inch line, set concentrically. Stuffing boxes and glands are provided at the surface to hold the pressure, and allow for expansion of the different pipes. Two sets of holes are drilled at

the bottom of the 6-inch pipe, the lower group being used as a sulphur strainer, the sulphur entering the pipe through these holes. The upper group of holes are used as outlets for the hot water pumped into the wells. Between the groups of holes is a seat or seal which supports a string of 3-inch pipe. The 1-inch air line is supported from the top of the well by means of a coupling on the stuffing box. The procedure of steaming a well is as follows. The water from the plant, heated to approximately 330°F., is forced down into the well between the 3-inch and the 6-inch pipes at a pressure of 100–250 pounds. This water,

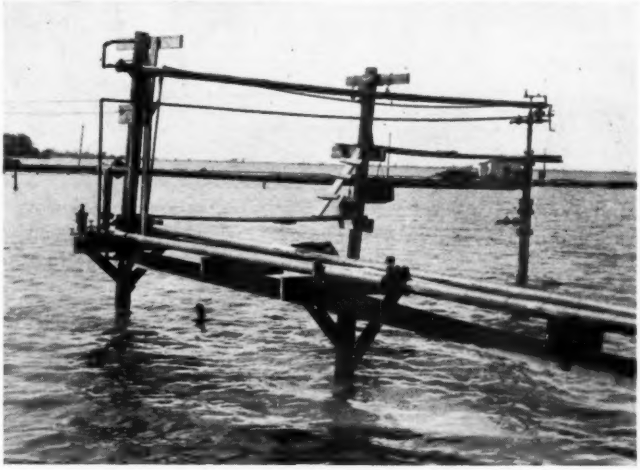

FIG. 16.—Operating sulphur well.

being of 0.9 specific gravity, rises to the top of the dome, melting the sulphur as it rises. The melted sulphur, with the specific gravity of about 2.0, drops to the bottom of the well, where it is forced up the 3-inch pipe a short distance by the dome pressure. The sulphur is then pumped to the surface by means of air which enters the 1-inch pipe and mixes with the sulphur, so changing its specific gravity that the sulphur flows readily to the surface. Under certain conditions, sufficient sulphur is melted by the water furnished the well so that the well operates for weeks or months at a time. Under other conditions, sufficient sulphur is not melted and the sulphur elevation decreases so that hot water enters the 3-inch pipe. This hot water comes to the surface instead of the sulphur, and flashes into steam at atmospheric pressure. The well is then said to "blow." Air is then cut off from the

well and water is pumped down the 3-inch and 6-inch pipes until sufficient sulphur is again melted, which is generally about a 3-hour period.

It is not necessary to refine sulphur as produced by the Frasch process. Table VII shows a tabulation of analyses of sulphur as produced at Barba, Louisiana.

TABLE VII

SULPHUR ANALYSIS FROM FIVE WELLS IN OPERATION, MARCH 3, 1933*
(Percentage)

	Well 38	*Well 40*	*Well 41*	*Well 43*	*Well 48*
Moisture	0.084	0.095	0.115	0.116	0.119
Ash	0.000	Trace	Trace	Trace	0.000
Sulphur	99.914	99.898	99.873	99.875	99.878
Organic matter	0.002	0.017	0.012	0.009	0.003
Sulphur—dry basis	99.998	99.983	99.988	99.991	99.997

* Lawrence O'Donnell, "Mining Sulphur from Lake Peigneur Deposit at Barba, Louisiana," *Thesis Graduate School of Tulane University* (New Orleans, Louisiana), p. 42.

MINING EFFICIENCY AT BARBA, LOUISIANA

Based on the experience of older sulphur-mining operations, the power plant at Barba, Louisiana, was designed for a capacity of approximately 200 long tons of sulphur per day. The production has been far greater than this amount, and reached more than 1,200 long tons of sulphur per day at times. This success is due in part to a thorough understanding of mining conditions on the Lake Peigneur dome by the field operation crew, together with the most efficient operation of the power plant. The very modern and efficient machinery also is a contributing factor to the phenomenal success. In the mining operations, a great deal of study has been given to the principles of thermodynamics involved.

The yearly production, and the total production to 1935, are shown in Table VIII.

TABLE VIII

SULPHUR PRODUCTION JEFFERSON LAKE OIL COMPANY, JEFFERSON ISLAND DOME

	*Tons**
1932	13,401
1933	304,928
1934	76,135
Total	394,464

* State of Louisiana, Department of Conservation, New Orleans, Louisiana.

The successful mining of sulphur since first begun by Frasch in 1893 has involved the solution of many difficult mechanical problems. The process has been perfected to the most minute detail. However, there have been very few changes in the basic Frasch process. Most

of the deposits mined to date have been mined under ideal conditions. That is, the deposits are on dry land, and not at a great depth. Future deposits no doubt will have to be mined under the difficulties imposed by swampy lands and greater depths. In the mining of all of these domes the question of costs is involved. Added to the high production costs associated with extensive mining operations, are increased taxation and excessive royalty demands. For this reason, all new mines involving higher costs must be considered carefully, and there is always a probability of increased competition from pyrites and by-product sulphur.

APPENDIX

TABLE I

LOG OF WELL NO. 1, JEFFERSON LAKE OIL COMPANY, INCORPORATED

Depth in Feet	*Formation*
6	Water
18	Muck or mud
20	Gumbo
35	Sand
40	Blue gumbo
66	Sand
123	Alternating 5- to 10-foot beds of sand and gumbo
153	Sand
168	Gumbo
210	Sand—went through log at 180 feet
220	Gumbo
260	Sand
269	Gumbo
319	Sand
402	Sand and gravel
433	Soft sand and gumbo
513	Broken gumbo—cypress log at 465 feet
551	Sand and gravel
563	Soft lime
666	Hard sand and gravel
683	Hard sandy limestone—top of cap
703	Sand, shale and broken lime
867	Sulphur formation
870	Lime and anhydrite
1,136	Rock salt, bottom of hole

TABLE II

LOG OF WELL NO. 10, JEFFERSON LAKE OIL COMPANY, INCORPORATED

Depth in Feet	*Formation*
9	Water
17	Silt
78	Soft gumbo
516	Sand and gravel
522	Gumbo
591	Sand and gravel
736	Gumbo
896	Sandy shale and gumbo
916	Hard sand
956	Calcareous shale

TABLE II (*Continued*)

LOG OF WELL NO. 10, JEFFERSON LAKE OIL COMPANY, INCORPORATED

Depth in Feet	*Formation*
996	Hard sand and gravel
1,114	Hard sand and gravel, layers of gumbo
1,116	Hard lime
1,122	Soft lime
1,155	Hard sand, colored green
1,235	Sand and gravel
1,250	Tough gumbo
1,260	Gummy lime
1,263	Lime rock
1,288	Gumbo
1,312	Layers hard and soft sand
1,329	Sand
1,341	Sand and shale. H_2S present in dark shale
1,397	Hard sand
1,403	Sand, shale, and lime
1,414	Gummy lime, tough
1,421	Gumbo and lime rock
1,440	Hard sand cored
1,448	Gumbo and lime
1,455	Lime and sand, small sulphur crystals, slight oil showing
1,465	Gumbo and lime
1,467	Hard sand
1,486	Gumbo, shale, and lime
1,876	Broken lime rock, very greasy
1,932	Broken lime and shale
1,945	Very hard black lime rock
1,954	Broken lime and shale
1,973	Sand and shale
2,047	Hard broken lime—oily
2,057	Soft sand and shale; white anhydrite
2,168	Salt. Bottom of hole

Well discontinued after drilling into salt. Considerable oil showing immediately above salt. No gas pressure.

TABLE III

DESCRIPTION OF CORES FROM WELL NO. 36, JEFFERSON LAKE OIL COMPANY, INCORPORATED

By R. Dana Russell

Depth in Feet	*Description*
591–604	Gumbo and sandy shale, with fragments of limestone, cemented with calcite. This section of core probably represents upper porous portion of cap rock, mixed with overlying sediments
604–613	Medium-to-fine-grained crystalline limestone, light-to-dark gray, with faint irregular banding. Limestone has been brecciated and recemented with coarsely crystalline white calcite. Some fragments show spotted appearance, due to presence of larger crystals (0.1–1 mm. in diameter) of calcite in very fine-grained, darker matrix. (Foregoing description is typical of most of limestone part of the cap rock, except for its lowermost portion.) Veinlets of pyrite and bands high in percentage of pyrite are common. No sulphur was seen
613–618	Black calcareous shale, with grains and pebbles of limestone. Lower part of core shows veinlets and small irregular patches, up to 0.25 inch in diameter, of opaque sulphur, with small amount of clear yellow sulphur. (Sulphur in this core occurs in two different forms, readily distinguishable by the unaided eye. One type is clear, yellow, and obviously crystalline; the other is semitranslucent-to-opaque, and dull yellow-white in color. The latter is either cryptocrystalline or amorphous.)

TABLE III (*Continued*)

DESCRIPTION OF CORES FROM WELL NO. 36, JEFFERSON LAKE OIL COMPANY, INCORPORATED

By R. Dana Russell

Depth in Feet	*Description*
622–624	Dark gray, fine-grained massive limestone, somewhat porous, which has been brecciated and recemented with veins of coarse-grained, white calcite. Clear yellow type of sulphur occurs as veinlets, as irregular areas up to 0.5 inch in diameter, and as cavity filling
640–643	Principally gray limestone, locally brecciated and locally porous, with coarse white calcite filling cavities. Clear yellow sulphur and a little opaque sulphur present as veinlets and scattered crystals. A few scattered crystals of pyrite present. Lower few inches of core consists of sand composed of limestone grains
650–653	Upper part, greatly brecciated gray limestone, with scattered grains of pyrite. Percentage of sulphur much lower than in preceding core. Lower part, unconsolidated and with grains of quartz, chert, some limestone, and some sulphur
653–657	Similar to 650–653. Upper part, limestone like that in preceding core, except that percentage of sulphur is higher. Lower part, sand similar to that in preceding core, saturated with oil in bottom of core
657–665	Medium-to-dark gray limestone, brecciated and recemented with coarse white calcite which predominates in amount over limestone in most of core. Clear yellow sulphur occurs as veins and cavity filling, increasing in amount toward bottom of core
669–670	Sand consisting of grains of limestone, calcite, and sulphur, with a few quartz grains. One piece of black shale noted
670–674	Fine-grained, massive, medium-to-dark gray limestone, veined with white calcite and somewhat porous. A few minute crystals of pyrite. Sulphur of both types plentiful, occurring as veinlets, cavity filling, disseminated crystals, and irregular patches
685–689	Limestone gouge with clear yellow type of sulphur makes up upper part of core. Sulphur in core is later than faulting which produced gouge, as it is not sheared. Gouge grades downward into limestone like that at 670–674. A few grains of black chert in lower part of limestone
693–697	Upper half, quartz sandstone, with included fragments of clay and silt, well cemented with calcite. A few traces of clear yellow sulphur. Lower half is fine-grained dark gray massive limestone, with veins and crusts of pyrite. Clear yellow type of sulphur present in considerable amounts
708–711	Dark gray limestone with scattered crystals and spots of pyrite, brecciated and recemented with coarse-grained white calcite. Lower part, higher percentage of white calcite and more porous. Sulphur of both types, chiefly as cavity filling. Opaque type coats clear yellow type, suggesting that it is later
718–722	Same. Percentage of sulphur of opaque type increases from 718 down to lower part of core, where it greatly prodominates over clear yellow type. A few small pieces of sandy limestone
729–732	Lower percentage of white calcite. One piece of core shows long radiating needles of clear yellow sulphur. Only one fragment of sandstone
748–751	Gradational series from dark pure limestone through sandy limestone to calcareous sandstone. Clear yellow type of sulphur present throughout. Sand grains consist principally of quartz and black chert. One fragment of calcareous shale
751–755	Black, fine-grained, banded limestone, spotted with larger crystals of white calcite and a few of barite. Pyrite. Brecciation less pronounced than in most preceding samples; percentage of white calcite lower. Clear yellow sulphur, principally as veins, with some filling cavities
755–759	Same, except barite more common, some crystals 0.25 inch long
772–774	Massive, black limestone, brecciated, but with very little recementation. Quartz grains common in cracks and some in limestone. Lower part, considerable pyrite as isolated crystals, ordinarily oxidized black on surface.

TABLE III (*Continued*)

DESCRIPTION OF CORES FROM WELL NO. 36, JEFFERSON LAKE OIL COMPANY, INCORPORATED

By R. Dana Russell

Depth in Feet	*Description*
	Clear yellow sulphur as veinlets, cavity filling, and as isolated crystals and irregular areas in limestone
785–790	Upper part, medium-to-light gray, fine-grained, porous limestone. Much clear yellow variety of sulphur, and some of opaque type, both as cavity filling. Opaque type seems later than clear type. Lower part, mixture of gray calcareous shale, and of sandstone with many grains of black chert. Clear yellow sulphur in matrix around sand grains, and as vein-like masses
790–794	Partly soft, white chalk, with irregular patches and veinlets of opaque type of sulphur. Remainder massive, fine-grained, porous gray limestone with small amount of opaque variety of sulphur
804–807	Partly calcareous sandstone with many black chert grains, containing a few grains of clear yellow sulphur. One piece of fine-grained black limestone has been brecciated and recemented with fine-grained white calcite. Remainder of core, medium-to-dark gray fine-grained porous limestone, with some opaque sulphur. Small crystals of pyrite are locally plentiful.
816–820	Medium-to-light gray fine-grained massive limestone, somewhat porous, with considerable opaque sulphur and some of clear yellow type, as irregular patches, veins, and cavity filling
823–827	Very porous fine-grained dark gray limestone, brecciated in a few places and recemented with fine-grained white calcite. Opaque type of sulphur as cavity filling, as small irregular patches, and in wisp-like areas consisting of series of very thin sub-parallel bands separated by thin bands of black limestone. Two or three fragments of calcareous sandstone like that in 810–813.
832–835	Fine-grained medium-to-dark gray limestone, including angular fragments of light gray-to-white limestone up to an inch in diameter. Dark limestone contains opaque sulphur as irregular areas, veins, and a few wisp-like patches. A little clear yellow sulphur in included fragments of light-colored limestone
835–838	Upper part, same as 832–835. Lower part, fine-grained light gray gypsum and calcite with a few larger crystals of gypsum up to 0.5 inch in diameter. Opaque sulphur and some clear yellow sulphur as cavity filling and coating surfaces of cracks
838–841	Same as lower part of preceding, except small amount of anhydrite
	Bottom of hole

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STUDY OF VICKSBURG GROUP AT VICKSBURG, MISSISSIPPI[1]

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AND
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ABSTRACT

The literature dealing with the history of the Vicksburg group at Vicksburg, Mississippi, is reviewed and summarized. A discussion of the stratigraphy of the exposed strata is given. The foraminiferal content is considered in detail, and a check list is presented.

INTRODUCTION

The marine beds exposed at the classic locality at Vicksburg, Mississippi, were among the first in the Gulf Coast to be examined scientifically, and have been treated in many papers. A large number of these, however, were written at an early date and were not intended primarily for geologists, paleontologists, or stratigraphers. Consequently, from much of the early literature little can be learned that is precise and definite. Vicksburg, Mississippi, constitutes the type locality for the Vicksburg group, yet no particular exposure in the vicinity of Vicksburg has been clearly designated as the type, and obviously it is difficult to decide which formation of the group is typical.

The stratigraphic paleontologist must decide what the Vicksburg is, and what makes up a Vicksburg fauna. Numerous species of *Foraminifera* have been described from the various formations of the group, but for purposes of stratigraphic correlation it is necessary to know more; that is, whether or not these fossils are short-ranged,

[1] Manuscript received, August 8, 1935. Published by permission of J. S. Ivy of the United Gas Public Service Company, Houston, Texas.

[2] Paleontologist, United Gas System. The writers wish to express their gratitude for the assistance rendered in the field by Jackson Young and Preston Fergus of the United Gas Public Service Company. The writers are also indebted to Merle C. Israelsky and Henry V. Howe for their aid and constructive criticism. Joseph A. Cushman was kind enough to check the writers' determinations and to describe many of the new species. Acknowledgment is likewise made of the painstaking efforts of E. D. Meredith and J. C. Albertson of the mapping and reproduction department of the United Gas Public Service Company.

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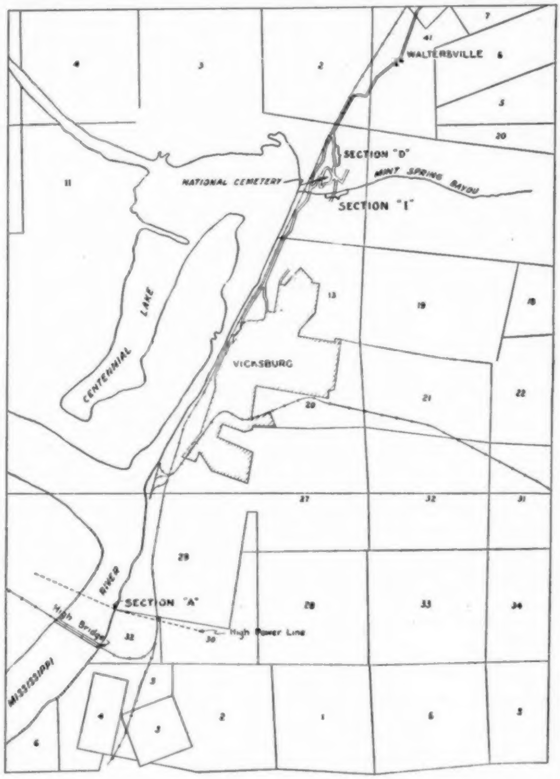
persistent, and diagnostic. This paper attempts to provide some of this information through a careful study of the entire marine section in the bluffs at Vicksburg.



KEY MAP SHOWING LOCATION OF SECTIONS IN VICINITY OF VICKSBURG

FIG. 1

No single exposure was found which included the entire interval from Catahoula above to Forest Hill below, but by combining two near-by exposures, such a section was constructed. The exposure on the road between Waltersville and the National Cemetery composes

the upper part of the section; that on Mint Spring Bayou composes the lower. The section on the river near the power tower is also shown because it is the most conspicuous and most easily accessible, contains excellent exposures of Mint Spring marl, and is possibly that which Hilgard published. A short section at the Byram type locality is added for comparative purposes.

The exposures were studied and samples collected during the early part of August, 1934, when the Mississippi River was very near its minimum level for the year. Vertical intervals were measured with the aid of a hand level, and horizontal distances estimated. In obtaining samples for microscopic examination, care was taken to dig deeply enough to secure material which was at least comparatively unweathered.

In the laboratory a large portion of each sample was carefully washed and the residue treated with bromoform to concentrate the *Foraminifera*. Detailed slides were made of the species from each sample, and in addition the bromoformed residue was examined for large or broken specimens which failed to float. The writers feel that this study presents a reasonably complete picture of the foraminiferal content of the marine strata of Vicksburg.

HISTORY

The first scientific mention of the marine beds exposed at Vicksburg, Mississippi, seems to have been that of Conrad,[4] which appeared in print in March, 1846. The following paragraph indicates his opinion at that time.

> Since I discovered the Eocene formation in Maryland in 1830, my own researches and those of others have proved its wide extension in the southern and southwestern states, and I now propose to publish descriptions and illustrations of most of the organic remains of that formation in the pages of this Journal. The development of the Eocene is much greater than was supposed, in consequence of its embracing a white friable limestone formerly referred to the Upper Cretaceous period. In reviewing the organic remains of that rock, I cannot resist the conviction that it is so nearly of the same age with the Eocene sands of Alabama, Mississippi, Louisiana, etc., that it may not with propriety be referred to an earlier era. The occurrence of what were supposed to be remains of *Enaliosauri*, now proved by Mr. Owen to be more of a cetaceous character; the genus *Plagiostoma*, *Gryphaea vomer*, (Morton), and one or two other secondary forms, led me to believe that the limestone in question was a connecting link between the secondary and tertiary strata.

[4] T. A. Conrad, "Observations on the Eocene Formation of the United States, with Descriptions of Species of Shells, etc., Occurring in It," *Amer. Jour. Sci.* (2), Vol. 1 (1846), pp. 209–10.
The Tombigbee River was spelled Tombeckbee at the time this was written.

But I now find the group of fossil genera to have so decided an affinity with that of the Eocene period, that I confidently class the whole white limestone of the southern parts of Alabama and Mississippi with the strata of that era. This limestone is extensively developed in Clarke Co., Alabama, where the remains of *Zeuglodon* were found and transmitted to me in 1834 by Mr. Cooper of Claiborne. Six miles west of Claiborne I examined this rock in the banks of a millstream and collected *Scutella Rogersii*, *Pecten Poulsoni*, and *P. perplanus*, etc. Between Claiborne and St. Stephens it forms hills of considerable elevation, and abounds in that fine fossil, *Plagiostoma dumosum*. At St. Stephens, on the Tombeckbee, this limestone constitutes an elevated bluff and abounds in *Nummulites Mantelli*, *Plagiostoma dumosum*, *Ostrea cretacea*, etc. At Vicksburg, the *Pecten Poulsoni* is common to this rock and to the Eocene sand, and the *Zeuglodon* was found on the Washita river in similar sand. . . .

Shortly afterward, Conrad[5] examined the fossils from the Vicksburg locality in a more careful manner, and altered his views somewhat, as may be seen from the following.

While collecting the organic remains of Warren County, Mississippi, I noticed a few shells which appeared to be identical with species from Claiborne, Alabama, but since I have carefully compared them in my cabinet, they prove to be distinct; and it is very remarkable that of the one hundred and three species of fossils found near Vicksburg, not one can be identified with a species of the Eocene of Maryland, Virginia, or Alabama. There is a species of *Trochus* resembling *T. agglutinans;* but the specimen is too imperfect to decide whether it agrees with the fossil *T. agglutinans* of Georgia. The Vicksburg group has decidedly more affinity with the Eocene group than with that of the Miocene, for there is only one species that closely resembles a Miocene fossil. The limestone of Clarke County, Ala., and of St. Stephens on the Tombeckbee, contains *Nummulites crustaloides* and *Pecten Poulsoni*, (Morton), two fossils which abound in the Vicksburg deposits, and this limestone is therefore probably of the same age as the tertiary beds of Vicksburg. This formation marks a distinct era in the American tertiary system, intermediate to the Eocene and Miocene formations, but more nearly allied to the former, and perhaps it will be proper to class it as a subdivision of the Eocene.

Conrad also includes a short correlation table which classifies the Vicksburg deposits as "upper or newer Eocene." It will be noticed in the preceding paragraph that he makes use of the term "Vicksburg group," apparently for the first time; however, it is doubtful that he intended to use the term in a stratigraphic sense, for where he says, "The Vicksburg group has decidedly more affinity with the Eocene group than with that of the Miocene," it appears that he is speaking of faunal assemblages rather than of stratigraphic units. Also, it will be observed that Conrad at this time decided that the Vicksburg beds

[5] T. A. Conrad, "Tertiary of Warren Co., Mississippi," *Amer. Jour. Sci.* (2), Vol. 2 (1846), pp. 124–25.

occupied that intermediate position between Eocene and Miocene for which the age name Oligocene[6] was later proposed in Europe.

In another paper of the same year, Conrad[7] discusses at greater length the topography and geology of the Vicksburg region, particularly the character and appearance of the outcrops, and describes in some detail the loess, which he calls "Vicksburg fossiliferous loam," overlying the marine deposits. He repeats some of his previous remarks concerning the marine beds, and in addition, says:

> . . . the sides of the hills and ravines are whitened in many places by the shells which have been washed out of the ferruginous marl or fossiliferous mixture of sand and clay. The strata appear to be nearly horizontal and the greatest elevation about sixty feet above the ordinary high-water level. The lowest stratum exposed is a bluish compact limestone, which is quarried for the purpose of paving the streets of Vicksburg. It is full of shells and casts of shells of such species as are common in the marls above. One of the most abundant bivalves is *Pecten Poulsoni*, (Morton), a species occurring in the white limestone near Claiborne, Alabama. A very thin wafer-shaped *Nummulite*, described by Dr. Morton, is common in the limestone as well as in all the strata above, and connects the formation of Vicksburg with the Eocene white limestone of St. Stephens, Alabama. A new species of *Pinna* is one of the most striking fossils of the limestone at Vicksburg, and which is rare above it. Over this rock are various strata of sandy marl, sometimes indurated and ferruginous, clay, and clay and sand mixed, all of which are very prolific in fossil shells. Near the summit of the Eocene are beds of coarse gravel mixed with whole shells and fragments. . . . In most of the strata here, small and large fragments of shells are very abundant, some of which are waterworn and others not in the least abraded. Occasionally we find a black waterworn shell just in the proportion to the others as we see them on the sea beach of New Jersey. The vicinity of an ancient sea beach is strongly indicated by the phenomena of these strata, which is not the case at Claiborne. Bivalves with connected valves are rare, fragments abundant, and the many water-worn specimens all tend to prove the action of the surf. In the clay stratum of the upper portion of the formation, the shells in some rare instances retain a trace of their original colors and their polish is fully equal to that of recent shells, though they become chalky on exposure to the sun. The *Cardita planicosta*, which so generally prevails in Eocene deposits, is unknown here, and the *Crassatella alta* of Claiborne is also absent, but there is an allied though very distinct species.

The preceding paragraph indicates that Conrad had by this time given some thought to the stratigraphy and lithology of the Vicksburg beds, even to the point of forming an opinion as to their mode of deposition, although his remarks are brief. His views concerning

[6] Beyrich, "Stellung der hessischen Tertiarbildungen," *Berl. Akad. Wissensch. Monatsber. für 1854* (1855), pp. 640–66.

[7] T. A. Conrad, "Eocene Formation of the Walnut Hills, etc., Mississippi," *Amer. Jour. Sci.* (2), Vol. 2 (1846), pp. 210–15.

the nearness of the old shore line seem particularly applicable to the Byram marl. Apparently, he divided the marine section roughly into underlying limestone and overlying beds of marl, sand, and clay. This seems to be the first division of the Vicksburg.

Conrad explains his failure to present an accurate section in the following manner.

The principal development of the Eocene is north of Vicksburg, and every ravine cuts through its various strata, but it is almost impossible to procure an accurate section of them, as they are universally sunk and displaced by land slides and subsidence. As near as I could ascertain, the Eocene strata rise to a level of sixty feet above the river when there is an ordinary freshet. The limestone, nearly on a level with the water, is the lowest stratum known, as debris and deposits from the river cover and conceal whatever may be at a lower level.

From this it would appear that he visited Vicksburg when the river was considerably above its low stage, and was thus unable to observe the lower portion of the section.

In 1847 Conrad[8] again published his views on the Vicksburg, once more using the term "Vicksburg group." A portion is quoted.

The Vicksburg group contains three species of bivalves which have much resemblance to Miocene fossils of this country. *Lima staminea* approaches *L. papyria; Corbula engonata* is allied to *C. inequalis*, Say; and *Nucula Vicksburgensis* to *N. obliqua*, Say.

I have not observed a recent species in this group, and yet it is decidedly more modern than that of the Claiborne sands; and as both deposits have but two species in common, I thought it advisable to designate the former, Upper or Newer Eocene, as the two divisions are more distinct than the Older and Newer Pliocenes.

A short time afterward Lyell[9] visited the locality, but commented only briefly on the occurrence of marine Eocene deposits at the base of the bluffs.

In 1854 Wailes,[10] state Geologist of Mississippi, published a bulletin on the geology of the state, in which he noted the presence of limestone and marl at Vicksburg, but added nothing to the previous observations of others.

Hilgard,[11] state Geologist of Mississippi, published in 1860 a

[8] T. A. Conrad, "Observations on the Eocene Formation, and Descriptions of One Hundred and Five New Fossils of That Period, from the Vicinity of Vicksburg, Mississippi, with an Appendix," *Proc. Philadelphia Acad. Nat. Sci.*, Vol. 3 (1846–47), pp. 280–81.

[9] Charles Lyell, *A Second Visit to the United States of North America*, Vol. 2 (1850), p. 208.

[10] B. L. C. Wailes, *Report on the Agriculture and Geology of Mississippi* (1854).

[11] E. W. Hilgard, *Report on the Geology and Agriculture of Mississippi* (1860).

bulletin on the geology of Mississippi in which the Vicksburg locality is discussed in a more detailed and coherent fashion than in any previous papers. The following paragraphs are quoted from the discussion under the title "The Vicksburg Group."

This interesting group, the highest of the marine eocene formation of Mississippi, and the only one which reaches the banks of the Mississippi River (at Vicksburg, where it was first studied by Conrad) occupies a narrow belt of nearly uniform width, southward of the territory of the Jackson Group, extending across the whole of the State, to the Alabama line, and thence to the Tombigbee River, where it forms the well-known bluff at St. Stephens. It is the only one of the marine stages of the eocene, which exhibits *crystalline limestones;* associated, however, with blue and white marls more or less indurate at times, as is the case with the other groups.

The marls, which have a tendency to be sandy rather than clayey, are the prevalent materials of the formation, and the chief repositories of the beautiful fossils of the group; they usually alternate with ledges of blue (or by oxidation yellowish) limestone, more or less sandy and glauconitic, and not unfrequently contain within their mass, indurate, rounded nodules, often very rich in fossils.

Here for the first time is the term "Vicksburg group" clearly and definitely used in the stratigraphic sense. On a succeeding page he takes up the bluff at Vicksburg in the following manner.

The general features of the Vicksburg bluff, which have already been mentioned, are exhibited in the following section. I regret that want of space precludes me from giving the detailed section, in which no less than 24 distinct strata, recognizable at most points, are exhibited.

SECTION OF THE BLUFF AT VICKSBURG, WARREN COUNTY

Feet	*Character of Strata*	*No.*
10–20	Calcareous silt with snails—Bluff Formation	7
5–20	Bluish and yellowish hardpan, often pebbles—Orange Sand	6
60–65	Alternating strata, 1–6 feet thick, of limestone and marl, containing the *Vicksburg fossils*, and some bands of non-effervescent, gray sand and clay	5
5	Black lignitic clay, and gray sand, with *Ostrea gigantea, Corbula alta, Natica mississippiensis, Cytherea sobrina, Madrepora Miss.*	4
25	Gray or black, lignitic clays or sands, with iron pyrites; exuding salts and sulphuretted hydrogen	3
3	Solid, lustrous lignite, with whitish cleavage planes	2
3	White limestone, of the Jackson Group?	1

Within the bed or series of beds, here marked as No. 5, the thickness of the several ledges varies greatly, so that detailed sections taken at different points of the bluff, exhibit variations in this respect. There are, however, several horizons which may be recognized almost everywhere, if the land slides which have taken place at many points, be left out of consideration. Thus, about 25 to 28 feet above No. 4 (containing the large oyster), we find a succession of 4 to 5 narrow bands (each 8 to 15 inches thick) of marl and laminated clay, which may be identified at all points, and acquire some importance from the circumstance that immediately beneath them, for the

next 10–12 feet, the purest and hardest limestone (from whose strata most of the building stones and flagstones used at Vicksburg have been quarried) is found. . . . Another stratum which, from the abundance and character of its shells, may be recognized easily, lies about 16 feet above the clay bands—a reddish, sandy marl, about 3 feet thick. Its shells are white, well preserved and easily washed out by the rains; among them, *Ostrea Vicksburgensis*, *Arca Mississippiensis*, *Cardium diversum*, *Dentalium Miss.*, and numerous species of *Pleurotoma* are conspicuous. Immediately beneath it lies a 3-foot bed of semi-indurate marl with large nodular masses of limestone, which can also be identified at most points; and the whole character of the strata from this bed upwards to the Orange Sand, shows a close correspondence with No. 6 of the Brandon section.

Hilgard had the following additional remarks to make about the basal strata.

Lignitic Beds.—At Vicksburg and at Brandon, lignitic clays and sands underlie the lowest visible strata of the Vicksburg Group. . . . At Vicksburg, about 25 to 30 feet of black lignitic clays and sands, and lower down, of lignite, underlie the calcareous marine strata. The lignite was supposed to extend to a considerable depth, but according to an observation made by Prof. W. D. Moore, at extreme low water, its thickness does not exceed 3 feet, it being underlain by a soft whitish limestone, of which he obtained a small specimen at the waters edge. It resembles the indurate marl of the McNutt Hills; the only fossil which is distinguishable on the specimen obtained (now in the cabinet of Oakland College) is a cast of *Cardium*, not sufficiently distinct to allow of observing the differences distinguishing the *Cardium diversum* of Vicksburg age from *C. Nicolleti* of Jackson and Claiborne.

Obviously, Hilgard examined the exposures with some care, but did not attempt to separate the strata into minor units. Since his is the first recognizable section, it seems appropriate to consider it the type. The character of his section approaches most nearly that of the conspicuous exposure on the river, north of the highway bridge and near the power tower. There, in addition to the marl and limestone beds, are excellent exposures of the beds of lignitic sand and clay. A unique feature is the occurrence of a thin limestone bed near water level, which is also found on Hilgard's section. The entire exposure is swept clean of debris and weathered material by the action of the river during high water, and is most obvious and striking, at least at low water.

In 1866 Conrad,[12] evidently influenced by the work of Hilgard, published a paper in which he correlates the basal shell beds at Vicksburg with those of Shell Bluff, Georgia; his correlation is solely on the basis of *Ostrea georgiana*. He gives these beds the name of "Shell

[12] T. A. Conrad, "Notice of New Group of Eocene Shells," *Amer. Jour. Sci.* (2), Vol. 41 (1866), p. 96.

Bluff group." His section, apparently modified from that of Hilgard, follows.

VICKSBURG BLUFF

	Feet
Calcareous silt with land shells of recent species	10–20
Bluish and yellowish hardpan, often pebbly, orange sand	5–20
Vicksburg Group	
Marl, etc.	60–65
Jackson Group	
Orbitolite limestone	
Shell-Bluff Group	
Black lignite, clay and gray sand with *Ostrea Georgiana* Conrad, *Corbula alta* Conrad, *Natica? Mississippiensis* Con., *Clavella Vicksburgensis* Con., *Triptonopsis subalveatus* Con., *Busycon nodulatum* Con.	5
Gray or black lignitic clays and sand	25
Solid lustrous lignite	3

During the course of the same year, Hilgard[13] wrote a reply to Conrad's paper, in which he completely contradicts Conrad's correlation, maintains that the "Shell Bluff Group" lies above rather than below the Jackson, and rebukes him for proposing to make a group of a 5-foot bed of clay.

In 1885 Meyer[14] included in his rather lengthy discussion of the "Southern Old-tertiary" a section at Vicksburg. The following is quoted.

Profile at Vicksburg, Miss.—Directly in front of the national cemetery near Vicksburg there is a creek (bayou) forming a waterfall, at which the following facts can be observed: At the top there is a stratum with the "Vicksburgian" fossils; below this follows a stratum of limestone with *Pecten*, about thirty feet thick; at the base is a clayey stratum with fossils, which must be strictly separated from the upper ones. These strata may be called "Higher," "Middle," and "Lower Vicksburgian." The Higher Vicksburgian contains the fossils generally known as Vicksburg fossils. The Lower Vicksburgian is characterized at first sight by the absence of *Arca Mississippiensis* Conr., which is abundant in the Higher Vicksburgian. It is very interesting as containing a species of *Caecum* and two species of the Pteropod *Styiola*, two genera hitherto unknown in the American Old-tertiary. Though I have not found as yet the species mentioned by Conrad, the Lower Vicksburgian is apparently identical with that stratum which Conrad called Shell Bluff Group, in Vicksburg; but if so, this name cannot be used for the Vicksburg stratum, because it implies a parallelism with Shell Bluff, which is as yet entirely without any proof.

In Dall's[15] paper on the North American Tertiary, there is in

[13] E. W. Hilgard, "Remarks on the New Division of the Eocene, or Shell Bluff Group, Proposed by Mr. Conrad," *Amer. Jour. Sci.* (2), Vol. 42 (1866), pp. 68–70.

[14] Otto Meyer, "The Genealogy and the Age of the Species in the Southern Old-tertiary," Part II, *Amer. Jour. Sci.* (3), Vol. 30 (1885), p. 71.

[15] W. H. Dall, "A Table of the North American Tertiary Horizons, Correlated with One Another and with Those of Western Europe, with Annotation," *U. S. Geol. Survey 18th Ann. Rept.*, Pt. II (1896–97), p. 331.

addition to a general discussion of the Lower Oligocene of the southeastern United States, the following remark.

The Vicksburg deposits were first referred to the Oligocene (after that term had been invented by Beyrich in 1853) by Conrad[16] who indicated their equivalence to the "Older Miocene" of McCoy, and continued to regard the Santo Domingo beds as of the same age.

Casey[17] in 1901 took up the question of the division of the horizons in the section at Vicksburg. The following is quoted.

At Vicksburg there are two distinct horizons, as recognized by Meyer,[18] but very inadequately and in part erroneously elucidated by Hilgard. The lower Vicksburgian consists of alternate thin strata of gray sands, sandy clays and variably, but usually loosely, compacted white or gray limestone. The upper consists of a much thinner bed of more or less red-brown marl, often indurated into nodular masses, or subindurated, and without trace of limestone, having rarely, however, thin layers of glauconitic sands and comminuted shells, in which entire specimens when found are generally distorted by pressure.

The faunas of these two beds differ very markedly, and there are probably not one-half of the species of either common to the two. One of the chief points of distinction resides in the fact that *Orbitoides mantelli* is virtually altogether wanting in the lower or limestone and is abundant and fully developed in the upper or marl bed. As this species existed in Jacksonian times, however, it seems as though it must certainly occur in the lower Vicksburg limestone, but at any rate it is so rare that I have never observed a specimen. The incongruity, therefore, of calling the Vicksburg limestone an Orbitoidal limestone is sufficiently evident; possibly the error occurred by reason of the washing down into the ravines of some material from the upper marls.

The preceding discussion is interesting mainly because Casey attempts to divide the beds at Vicksburg. It seems difficult to imagine how he could have failed to observe the large *Foraminifera* in the limestone, had he given it even a casual examination. In a succeeding paragraph he goes on to say:

Mr. D. W. Langdon[19] enumerates the fossils collected by him at Byram station, on the Pearl river. They are all Vicksburgian with the exception of *Capulus americanus*, which is Jacksonian. As this species has never been found at Vicksburg, the presumption is that the Byram beds are older than the true Vicksburgian, and this is further borne out by the fact, which I have noted from personal observation, that the Byram deposit contains, besides

[16] T. A. Conrad, "Check List of the Invertebrate Fossils of North America, Eocene and Oligocene," *Smithsonian Misc. Coll. No. 200* (1866), pp. IV, 26, 37.

[17] T. L. Casey, "On the Probable Age of the Alabama White Limestone," *Proc. Philadelphia Acad. Natural Sci.*, Vol. 53 (1901).

[18] Casey says, "The two lower horizons of Meyer constitute, in my opinion, but one."

[19] D. W. Langdon, *Amer. Jour. Sci.*, Vol. 31, p. 205.

the species quoted by Mr. Langdon, a considerable number peculiar to it and apparently occurring nowhere else. The evidence adduced by Mr. Langdon would seem to show that there is a notable thickness of marine, though scarcely fossiliferous, deposits between the true Jackson and Byram, and it is probable that during this interval the Red Bluff beds were formed. The order of emergence of the various deposits—which were all more or less local—may therefore be stated to be: (1) Jackson stage, (2) Red Bluff substage, (3) Byram substage, and (4) Vicksburg stage.

In the preceding paragraph the term "Byram" is used, apparently for the first time, although its position in the column is incorrect.

Maury,[20] in a paper published in 1902, presents a comparatively accurate section as follows.

Section at Mint Spring Bayou.—A section of the Vicksburg limestone was made by Mr. Veatch, in 1900, along the course of Mint Spring Bayou, a small creek in the outskirts of Vicksburg. The strata are given in descending geological order:

		Feet
Loess and Orange sand	1. Yellow fossiliferous loess, *Helix* and loess *Kindchen*	75
	2. Orange sand	40
Vicksburg limestone	1. *Arca* bed. A highly fossiliferous, blue and red, ferruginous marl, very glauconitic	8
	2. Unexposed	1
	3. Hard, drab, fossiliferous limestone, glauconitic; forms the cap rock of the fourth falls	½
	4. Soft, blue, glauconitic marl	8½
	5. Indurated, fossiliferous, grayish marl, making a secondary cap	1
	6. Soft, yellow, fossiliferous marl, undermined at base of falls	4
	7. Slope between falls, unexposed	4
	8. Indurated gray marl with few fossils. Forms cap of third falls	2
	9. Soft, gray marl	3
	10. Gray sandstone	1
	11. Slope between falls, unexposed	3
	12. Hard gray limestone with *Crassatella* and *Cardium*. Upper six inches filled with *Pecten*. Forms cap of second falls	23
	13. Drab-colored marl, *Cytherea* bed	4
	14. Dark, bluish-black, laminated, somewhat micaceous, lignitic clay	9
	15. Slope between falls, unexposed	6
	16. Same as 14, with a few faint casts	7
	To water level of Centennial Lake	200

In 1915 Lowe[21] included in his bulletin on the geology of Mississippi a brief discussion of the Vicksburg group, containing a general description of the main features of the exposures at Vicksburg. There is nothing new with respect to the marine beds, but the term "Madi-

[20] Carlotta J. Maury, "A Comparison of the Oligocene of Western Europe and the Southern United States," *Bull. Amer. Pal.*, Vol. 3, No. 15 (1902), pp. 71–72.

[21] E. N. Lowe, "Mississippi, Its Geology, Geography, Soils, and Mineral Resources," *Mississippi State Geol. Survey Bull. 12* (1915).

son sand" is proposed for the sands between the marine Jackson and the marine Vicksburg.

Hopkins,[22] in a paper published in 1916, submits a rather generalized consideration of the exposures in the vicinity of Vicksburg. He speaks of the "Vicksburg limestone" instead of the Vicksburg group, following the lead of some of the earlier writers. A continuous composite section from Catahoula sandstone to Jackson is included; however, no attempt is made to separate the Vicksburg into its individual units. Sections of Vicksburg limestone are taken at Haynes Bluff and Waltersville, both near Vicksburg. In the description following the section, Hopkins notes the main divisions of the Vicksburg; that is, a central limestone member, with marls above and below; he also, however, includes a portion of the overlying unfossiliferous sand, which can be more logically referred to the Catahoula.

Credit for the most careful study of the Vicksburg must go to Cooke,[23] who analyzed the entire group, and who originated some of the names of the formations included in it. It is almost entirely his classification which is being used at the present time. A portion of the general discussion of the Vicksburg group is quoted.

VICKSBURG GROUP

In Mississippi the Vicksburg group falls naturally into three divisions, the upper, middle, and lower Vicksburg, which differ from one another in both lithology and fossils. The first of these, which corresponds to the "Higher Vicksburgian" of Meyer[24] and to the "Upper Vicksburgian" of Casey,[25] is herein named Byram calcareous marl; for the second, which is approximately equivalent to the "Middle and Lower Vicksburgian" of Meyer and to the "Lower Vicksburgian" of Casey, the name Marianna limestone, already in use in Florida, is available; the third includes two facies, a shallow-water or nonmarine facies in western Mississippi, which will be called the Forest Hill sand, and a marine facies in eastern Mississippi and western Alabama known as the Red Bluff clay. In the middle division, or Marianna, two subdivisions are recognized, herein named Mint Spring calcareous marl member and Glendon[26] limestone member. East of Clarke County, Alabama, the middle and lower Vicksburg are similar lithologically and are both included in the Marianna limestone.

[22] O. B. Hopkins, "Structure of the Vicksburg-Jackson Area, Mississippi, with Special Reference to Oil and Gas," *U. S. Geol. Survey Bull. 641*, Part II (1916).

[23] C. W. Cooke, "Correlation of the Deposits of Jackson and Vicksburg Ages in Mississippi and Alabama," *Jour. Washington Acad. Sci.*, Vol. 8, No. 7 (1918), pp. 186–98.

[24] Otto Meyer, *Amer. Jour. Sci.*, 2d ser., Vol. 30 (1885), p. 71.

[25] T. L. Casey, *Proc. Philadelphia Acad. Natural Sci.*, Vol. 53 (1901), p. 515.

[26] Cooke says: "The name Glendon limestone has been adopted, with my consent, by O. B. Hopkins (*U. S. Geol. Survey Bull. 661-H*, 1917), who had access to my notes and manuscripts."

In a later paper Cooke[27] discusses something of the history of the Vicksburg locality, and goes into a more detailed consideration of the Byram marl. He says:

> . . . but more detailed study of the mollusks and corals shows that the marl at Byram is of the same age as the upper shell bed at Vicksburg, and this correlation is entirely corroborated by the evidence of the Bryozoa and the Foraminifera.
>
> The Byram marl lies conformably upon the Glendon limestone member of the Marianna limestone. The relations of the Byram marl to the overlying Catahoula are conjectural. At Vicksburg the transition from one formation to the other is so gradual that deposition appears to have been continuous from the Vicksburg into the Catahoula, ...
>
> Although the Byram marl, being the formation from which Conrad obtained most of his fossils from Vicksburg and upon which he based his description of the Vicksburg group, is the type formation of the group, it is not nearly so conspicuous as the Marianna limestone, which underlies it, and this has given rise to the erroneous impression that the Vicksburg group consists chiefly of limestone.

It is interesting to note that Cooke considers the Byram to be the type formation of the Vicksburg group, although the present writers can not agree with him. Concerning Byram exposures at Vicksburg, Cooke says:

> Exposures of the Byram marl occur at several places near Vicksburg. The best and most complete is on the Park Road leading southward up the hill from Waltersville past the north side of the National Cemetery. Bed 1 of the following section, which shows the entire thickness of the Byram marl as well as parts of adjacent formations, was found in a ravine 11 feet below the wagon bridge on the east side of Waltersville.

SECTION BETWEEN WALTERSVILLE AND THE NATIONAL CEMETERY

	Feet
12. Loess	25
11. Coarse gravel, pebbles 2 inches in maximum length, in matrix of irregularly grained sand	13
Catahoula sandstone(?)	
10. Fine gray laminated sand	25
Byram marl	
9. Lower 10 feet consists of a shell bed with *Scapharca lesueuri*, etc., at base, overlain by $1\frac{1}{2}$ feet of brownish fossiliferous clay, grading upward into yellowish ferruginous, glauconitic sandy marl with shells. Upper part is prevailingly brown clay with patches of marl, with shells locally abundant. Top is yellowish-gray, sparingly glauconitic, ferruginous shell marl with *Ostrea vicksburgensis*, *Pecten poulsoni*, etc.	38
8. Gray or brown argillaceous marl and brown clay with occasional plant remains associated with mollusks. Shells especially abundant near the top. *Dentalium mississippiense*, *Pecten poulsoni*, etc.	4.5
Marianna limestone (Glendon limestone member)	
7. Gray glauconitic, somewhat indurated marl with poorly preserved fossils. Nodular in upper part	4.5

[27] C. W. Cooke and J. A. Cushman, "The Byram Calcareous Marl of Mississippi and Its Foraminifera," *U. S. Geol. Survey Prof. Paper 129-E* (1922).

6.	Blue-gray or gray fossiliferous glauconitic argillaceous marl with some stiff blue clay at top. *Lepidocyclina*.	4
5.	Gray marl, slightly indurated at top, which forms a projecting ledge over Nos. 3 and 4. The top is level with the floor of the bridge at the south end	5
4.	Stiff brown clay with thin partings of marl	1
3.	Gray or yellow marl with obscure fossils; a thin band of brown clay at bottom	1.5
2.	Hard pinkish-gray limestone with a little glauconite and fragments of *Pinna*, etc. A few inches at top consists of soft laminated gray marl with abundant *Lepidocyclina* and *Pecten poulsoni*	2
1.	Gray or cream-colored sandy marl, with flakes of mica and small grains of glauconite. *Pecten poulsoni* and fragments of other fossils. Thickness seen	1.5

The foregoing section constitutes, so far as the writers have been able to determine, the best and most complete exposure of Byram marl in the vicinity of Vicksburg. However, the writers are at a loss to decide how Cooke located the top of the Glendon limestone where he did in the section, since the Glendon is by definition a limestone. Lithologically, the beds marked No. 8 and No. 7 are similar, yet theoretically they lie on either side of the contact. From the lithologic standpoint, it appears more plausible to accept bed No. 2, a "hard pinkish gray limestone," as the top of the Glendon.

Later Cooke[28] decided that the Glendon deserved the rank of formation because

> beds of Glendon age are now known to have a wider distribution than the typical Marianna, to contain a large and characteristic fauna, and to transgress older formations.

He continues:

> It overlies the Marianna conformably. In the type area the formation consists of a series of ledges of hard, partly crystalline yellowish or pinkish limestone interbedded with softer strata of impure limestone, aggregating 18 or 20 feet in thickness. The formation probably extends westward as far as Mississippi River, where the hard ledges in the bluffs at Vicksburg are tentatively placed in the Glendon, but the identification of the Glendon limestone in western Mississippi is somewhat questionable.

He also remarks that he considers the "chimney rock" facies of the Marianna limestone in western Mississippi to be entirely replaced by the Mint Spring marl. He says:

> Between Vicksburg and Pearl River the Mint Spring marl occupies the entire interval between the Glendon limestone and the Forest Hill sand, but east of Pearl River it is overlain by a thickening wedge of Marianna "chimney rock."

[28] C. W. Cooke, "The Correlation of the Vicksburg Group," *U. S. Geol. Survey Prof. Paper 133* (1923).

CONCLUSIONS

From a study of the literature, it becomes evident that the exposures at Vicksburg have attracted the attention of many, but that in the majority of cases their examinations were cursory and their remarks not altogether enlightening. The work of Conrad is interesting for several reasons. In the first place, he used for the first time the term "Vicksburg group," although not in reference to a stratigraphic unit, as it is applied today, but to an assemblage of fossils. In the second place, his interest was first aroused by the limestone, the "Vicksburg limestone," so conspicuously exposed in the bluffs. Thus, this "Vicksburg limestone" more properly deserves to be considered the type formation of the Vicksburg, if there be any, than the Byram marl, as Cooke advocates, although Conrad apparently collected many of his Vicksburg fossils from the Byram. In the third place, Conrad soon recognized that the Vicksburg occupied an intermediate position between Eocene and Miocene, and was the first to refer it to the Oligocene, when that term came into existence.

The efforts of Hilgard are noteworthy because he first employed the term "Vicksburg group" in a definite stratigraphic sense; he studied the exposures at Vicksburg in some detail, and he published the first section showing the sequence of the strata. The papers of Meyer and Casey are of interest principally because they propose to divide the beds at Vicksburg. Cooke's work is naturally of considerable importance, since his classification of the Vicksburg group is the standard one.

Mint Spring marl.—In naming this member of the Marianna limestone, Cooke[29] makes the following remarks.

> The "chimney rock" facies of the Marianna limestone is replaced in western Mississippi by sands and shell marls for which the name Mint Spring calcareous marl is here proposed. The name is derived from Mint Spring Bayou, a small stream entering Centennial Lake just south of the National Cemetery at Vicksburg. The strata to which the name is applied are exposed beneath a waterfall in the lower course of the stream.

The writers propose to set the upper limit of the Mint Spring at the first limestone ledge, and the lower at the last fossiliferous bed. Between these limits are included 20–25 feet of marine strata, grading from sparingly fossiliferous lignitic sands and clays in the lower portion to sandy fossiliferous marls in the upper.

Marianna (?) *limestone.*—As previously stated, Cooke considers that at Vicksburg the Marianna limestone is entirely replaced by the

[29] C. W. Cooke, "Correlation of the Deposits of Jackson and Vicksburg Ages in Mississippi and Alabama," *Jour. Washington Acad. Sci.*, Vol. 8, No. 7 (1918), p. 195.

Mint Spring marl. Nevertheless, from the standpoint of lithology it seems plausible to accept the 15–20 feet of comparatively soft, white-to-cream-colored limestone, alternating with thin beds of chalky marl, as representing the Marianna. The strata in question are very well exposed at the main falls on Mint Spring Bayou, lying between the marls at the base and the hard limestone ledge at the top of the falls. The ledge, which is presumably Glendon, forms the cap of the falls, and the softer limestone beneath has weathered from under it. In addition, the foraminiferal content of the soft limestone is very similar to that of the type Marianna.

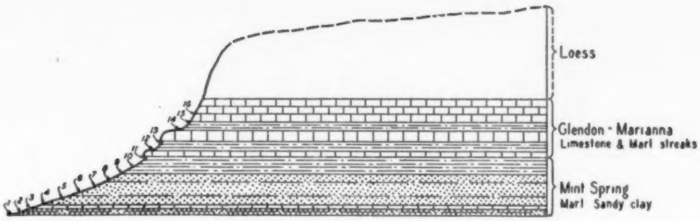
Glendon (?) *limestone.*—Cooke's lead is followed in referring the 20–25 feet of hard limestone interbedded with thin gray marl layers to the Glendon.

Byram marl.—The Byram is represented by 50–55 feet of gray-to-greenish gray, glauconitic, fossiliferous marl and clay. Its upper limit is determined by the unfossiliferous Catahoula sands, the lower by the first limestone ledge.

Conditions of deposition.—The depositional history of the strata exposed at Vicksburg began with the formation of the non-marine Forest Hill sands. Conditions were not favorable to marine life during the deposition of the lower, or sand and clay, portion of the Mint Spring, as is indicated by the presence of lignite, and by the sparsity of fossils. There was a more or less uniform gradation into a thoroughly marine phase, during which time the upper, or marl portion, of the Mint Spring was laid down. Throughout Mint Spring time, however, the water was shallow enough for the deposition of considerable sand. The water seems to have been considerably deeper during the formation of the limestone section, for the material of the marl streaks is uniform and fine grained, and the fossils show little evidence of having been rolled about. In Byram time the sea became shallower, as is evidenced by the polished and broken character of the fossils, particularly the *Foraminifera*. Increased amounts of glauconite and sand appeared. The shallow, warm character of the Byram sea is substantiated by the presence of such foraminiferal genera as *Camerina*, *Peneroplis*, and *Spirolina*.

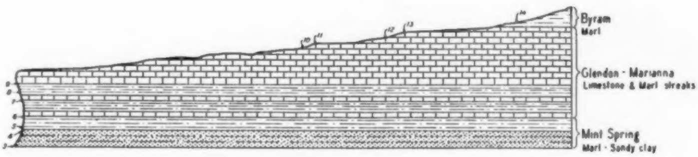
PALEONTOLOGY

The majority of the Vicksburg *Foraminifera* have been described by Cushman, Howe, Nuttall, and Cushman and Ellisor. Titles of their papers may be obtained by referring to the bibliography. All the species which it has been possible to identify are presented on the accompanying check list (Table I), which is believed to be reason-



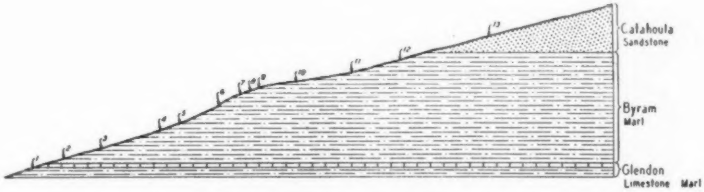
SECTION "A" ON RIVER AT VICKSBURG
Horizontal distance appr. 250'
Vertical scale

FIG. 2



SECTION "C" MINT SPRING BAYOU
Horizontal distance appr. 1000'
Vertical scale

FIG. 3



SECTION "D" NEAR WALTERSVILLE, MISS
Horizontal distance appr. 300'
Vertical scale

FIG. 4

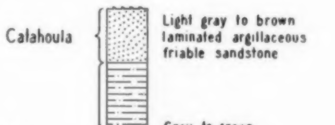


FIG. 5.—Idealized section at Vicksburg, Mississippi.

TABLE I

CHECK LIST OF VICKSBURG FORAMINIFERA

* *Lagena byramensis* Cushman (1929) is an *Entosolenia;* therefore *Entosolenia byramensis* Cushman (1935) is preoccupied

G: Type Byram section
D: Sec. "D," Waltersville

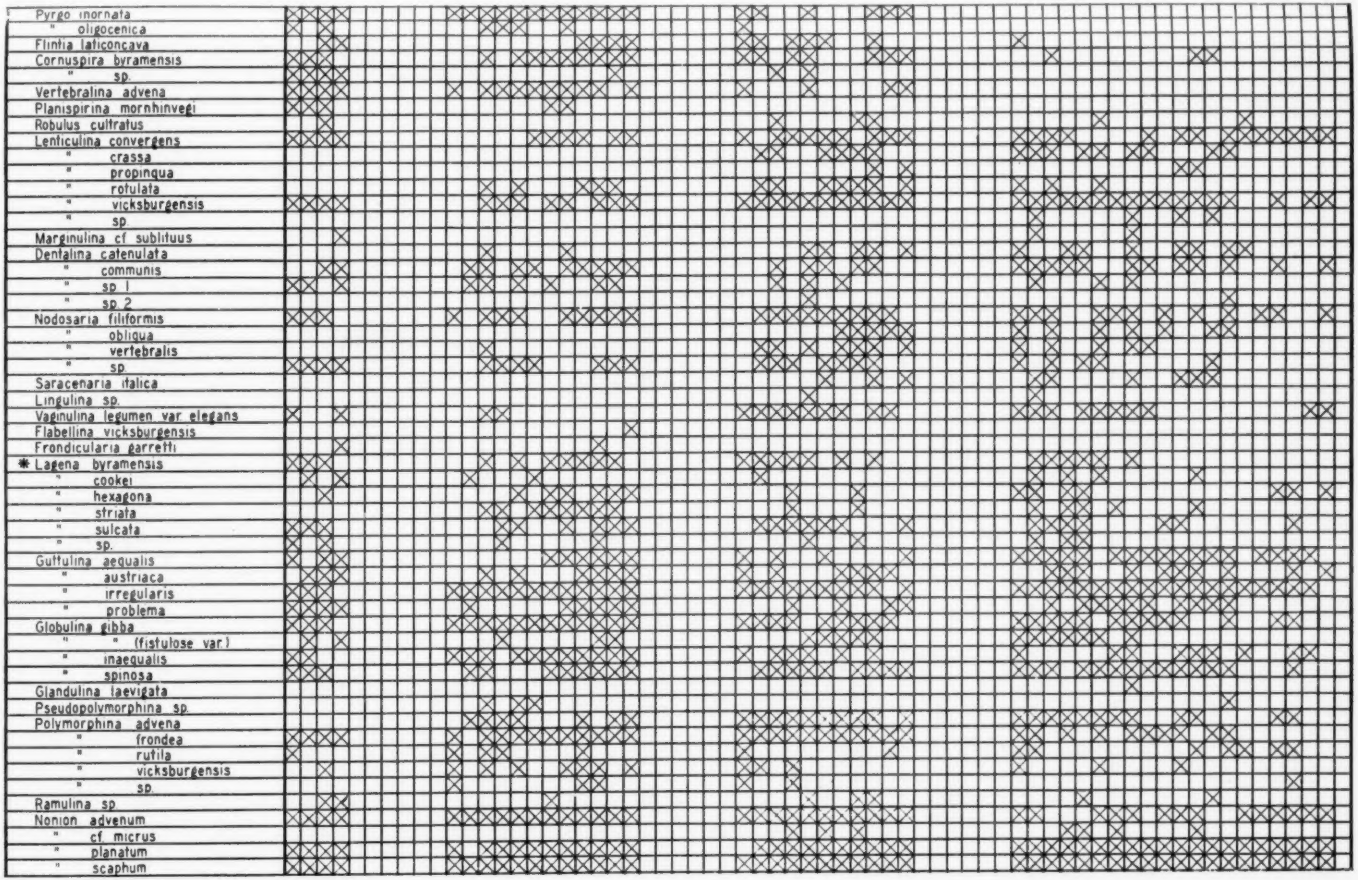
I: Sec. "C," Mint Spring Bayou
A-B: Sec. "A," bluff at Vicksburg

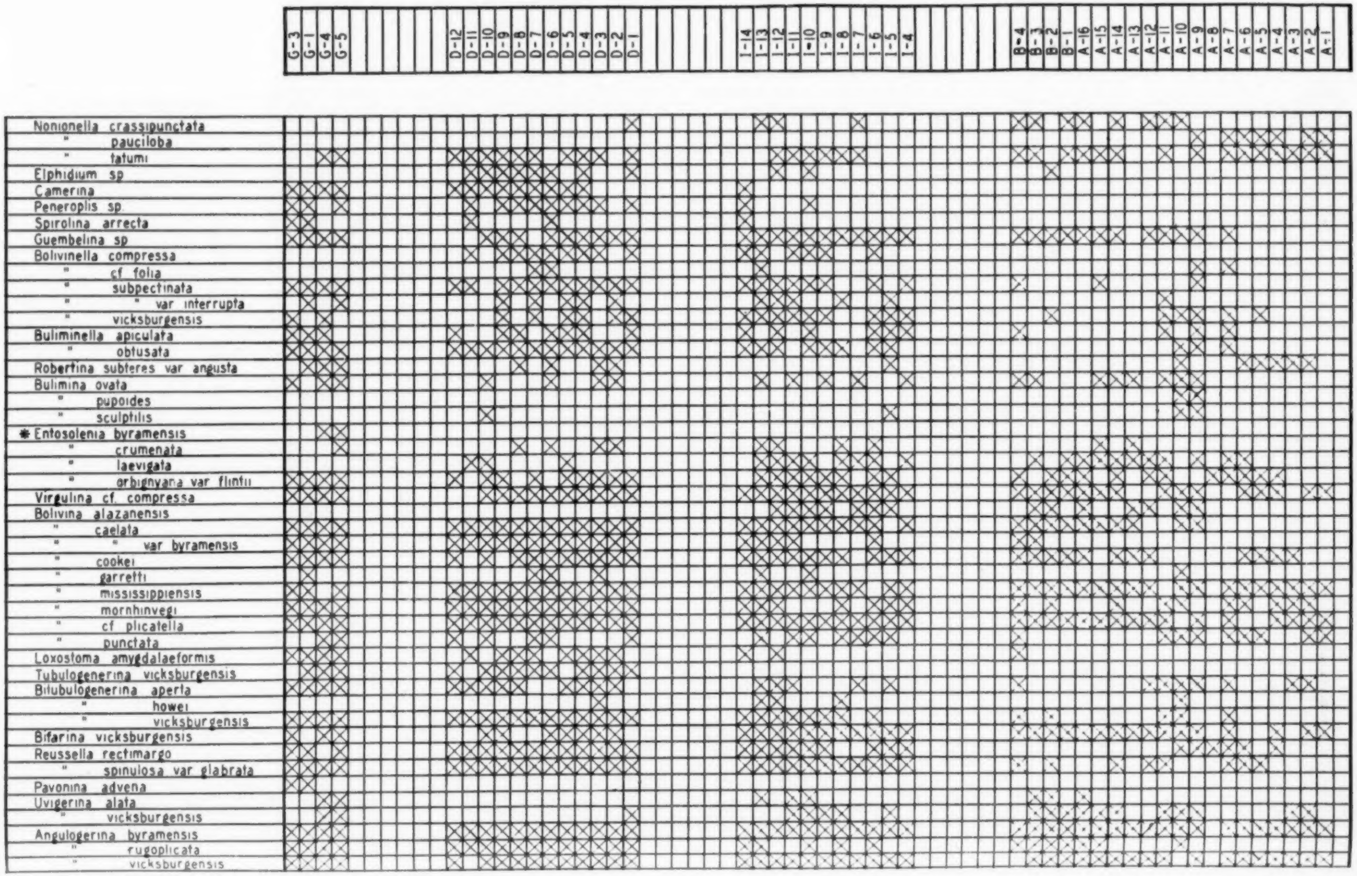
	G-3	G-1	G-4	G-5	D-12	D-11	D-10	D-9	D-8	D-7	D-6	D-5	D-4	D-3	D-2	D-1
Ammobaculites agglutinans										X						
Cyclammina sp													X			
Textularia agglutinans	X	X	X	X			X		X				X	X	X	X
" conica	X	X		X			X		X			X	X		X	
" mississippiensis	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X
" recta										X	X				X	
" subhauerii	X	X	X	X	X	X	X		X				X	X	X	X
" tumidula	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Gaudryina advena	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
" glabrata	X	X	X		X	X	X	X	X	X	X	X	X	X	X	
" youngi	X	X	X	X		X	X		X	X		X	X	X		X
" sp																
Clavulina byramensis (thin var)	X	X	X	X	X		X	X	X	X		X	X	X	X	X
" " (thick var)	X	X	X	X											X	X
Quinqueloculina bicostata	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X
" byramensis		X	X		X			X	X	X	X	X	X			X
" contorta												X				
" cookei	X		X		X		X	X	X		X		X			
" crassa	X	X	X	X			X		X			X			X	
" cf cuvieriana			X	X		X	X		X	X	X		X	X	X	
" lamarckiana	X		X	X			X			X			X	X	X	X
" limbata										X	X					X
" lustra								X			X					
" seminula	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
" tessellata	X			X		X	X	X	X		X	X	X	X	X	X
" vicksburgensis	X	X	X				X	X	X		X	X		X	X	
" vulgaris	X	X								X	X			X	X	X
" sp.	X	X											X	X		
Massilina crusta	X			X						X						
" decorata	X	X	X					X	X				X	X	X	
" glabricostata	X	X	X					X	X		X	X	X		X	X
" occlusa	X	X	X	X		X	X		X	X	X	X	X		X	X
Spiroloculina antillarum													X	X		
" byramensis	X	X	X						X	X	X	X	X			X
" grateloupi	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Articulina byramensis	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X
Hauerina fragillissima	X	X		X						X	X	X				
Triloculina mississippiensis	X	X	X	X							X	X				
" oblonga	X	X	X	X	X	X			X		X	X	X			
" sculpturata	X		X		X	X	X		X		X	X	X	X	X	X
" sp			X													

	I-14	I-13	I-12	I-11	I-10	I-9	I-8	I-7	I-6	I-5	I-4
Ammobaculites agglutinans											
Cyclammina sp											
Textularia agglutinans				X	X				X	X	X
" conica					X						X
" mississippiensis	X	X	X	X	X	X	X	X	X	X	X
" recta					X					X	
" subhauerii	X				X				X		X
" tumidula	X	X	X	X	X	X			X	X	X
Gaudryina advena	X	X	X	X	X	X	X	X	X	X	X
" glabrata	X			X	X				X		
" youngi	X	X		X						X	X
" sp											
Clavulina byramensis (thin var)	X	X	X	X	X	X	X		X	X	
" " (thick var)	X	X	X	X	X	X	X			X	
Quinqueloculina bicostata	X	X	X	X	X	X			X		
" byramensis	X										X
" contorta					X		X			X	X
" cookei	X										
" crassa		X			X					X	
" cf cuvieriana	X				X				X	X	X
" lamarckiana	X	X	X		X					X	
" limbata	X										
" lustra											
" seminula	X	X	X	X	X	X	X		X	X	X
" tessellata	X	X			X					X	X
" vicksburgensis	X	X							X		
" vulgaris			X								X
" sp.											
Massilina crusta									X		
" decorata		X	X	X	X	X	X	X	X	X	
" glabricostata	X	X	X	X	X				X	X	X
" occlusa	X	X		X	X						X
Spiroloculina antillarum	X		X		X					X	
" byramensis	X										
" grateloupi	X	X		X	X					X	
Articulina byramensis	X	X		X	X				X		X
Hauerina fragillissima	X										
Triloculina mississippiensis	X										
" oblonga	X		X		X					X	X
" sculpturata	X	X	X	X	X	X			X		X
" sp	X										

	B-4	B-3	B-2	B-1	A-16	A-15	A-14	A-13	A-12	A-11	A-10	A-9	A-8	A-7	A-6	A-5	A-4	A-3	A-2	A-1
Ammobaculites agglutinans																				
Cyclammina sp																				
Textularia agglutinans					X		X			X										
" conica										X	X	X	X							
" mississippiensis		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X
" recta	X																			
" subhauerii	X				X		X				X									
" tumidula	X	X	X	X	X		X		X	X	X	X	X	X					X	
Gaudryina advena	X	X	X				X		X	X	X	X	X	X						
" glabrata																				
" youngi									X				X	X						
" sp												X								
Clavulina byramensis (thin var)	X		X		X		X													
" " (thick var)																				
Quinqueloculina bicostata												X	X				X	X		
" byramensis																				
" contorta																				
" cookei																				
" crassa																				
" cf cuvieriana												X	X							
" lamarckiana											X									
" limbata																				
" lustra															X	X		X		
" seminula	X		X							X	X	X	X	X			X	X		
" tessellata														X						
" vicksburgensis																				
" vulgaris	X										X	X	X	X	X	X	X	X		
" sp.																				
Massilina crusta																				
" decorata	X	X	X	X	X	X	X	X	X		X	X	X	X					X	
" glabricostata										X		X		X						
" occlusa										X		X		X						
Spiroloculina antillarum												X	X							
" byramensis																				
" grateloupi																				
Articulina byramensis																				
Hauerina fragillissima																				
Triloculina mississippiensis																				
" oblonga																				
" sculpturata	X																	X	X	
" sp													X	X		X	X	X		

" sculpturata
" sp

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A-11
A-10
A-9
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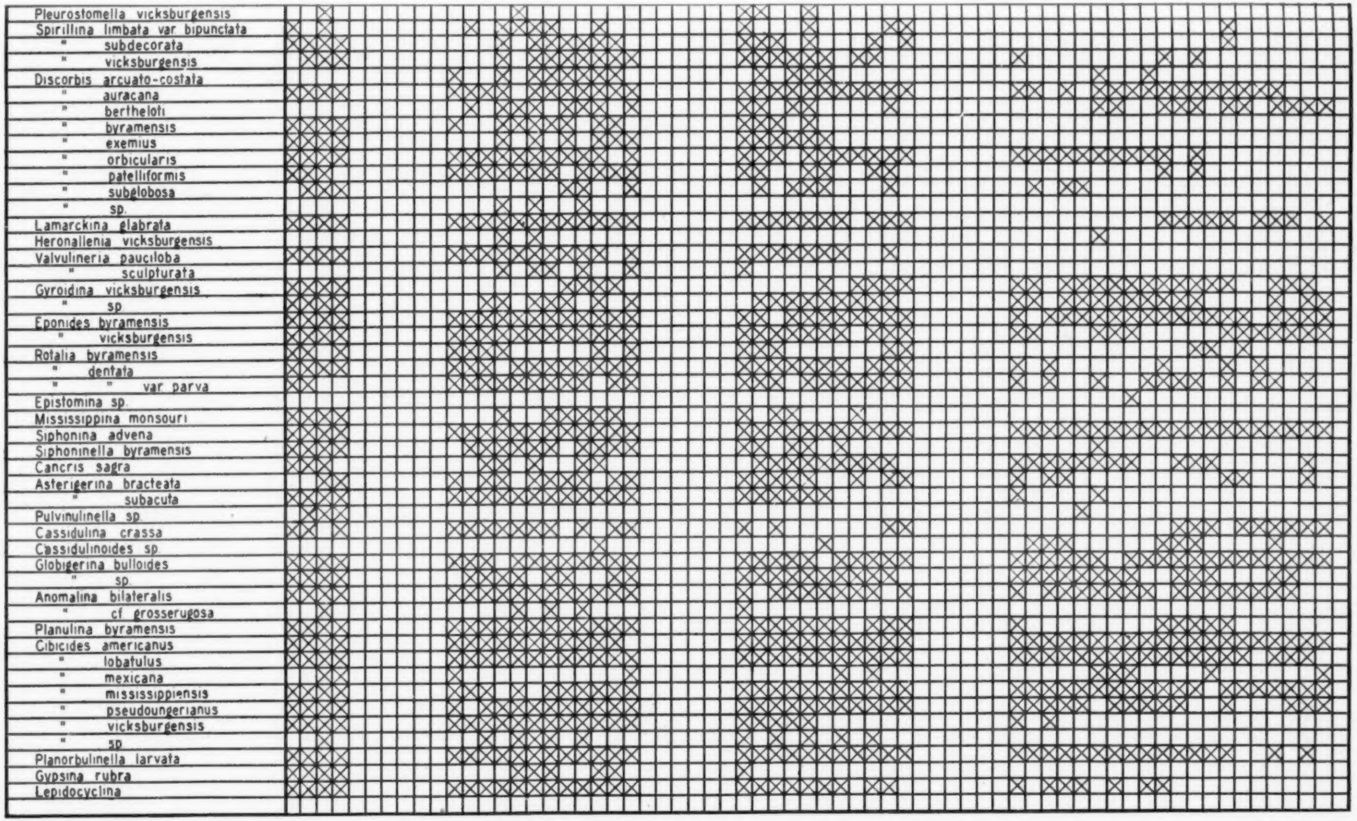
Nonionella crassipunctata
" pauciloba
" tatumi
Elphidium sp
Camerina
Peneroplis sp
Spirolina arrecta
Guembelina sp
Bolivinella compressa
" cf folia
" subpectinata
" " var interrupta
" vicksburgensis
Buliminella apiculata
" obtusata
Robertina subteres var angusta
Bulimina ovata
" pupoides
" sculptilis
* Entosolenia byramensis
" crumenata
" laevigata
" orbignyana var flintii
Virgulina cf. compressa
Bolivina alazanensis
" caelata
" " var byramensis
" cookei
" garretti
" mississippiensis
" mornhinvegi
" cf plicatella
" punctata
Loxostoma amygdalaeformis
Tubulogenerina vicksburgensis
Bitubulogenerina aperta
" howei
" vicksburgensis
Bifarina vicksburgensis
Reussella rectimargo
" spinulosa var glabrata
Pavonina advena
Uvigerina alata
" vicksburgensis
Angulogerina byramensis
" rugoplicata
" vicksburgensis



Pleurostomella vicksburgensis
Spirillina limbata var bipunctata
" subdecorata
" vicksburgensis
Discorbis arcuato-costata
" auracana
" bertheloti
" byramensis
" exemius
" orbicularis
" patelliformis
" subglobosa
" sp.
Lamarckina glabrata
Heronallenia vicksburgensis
Valvulineria pauciloba
" sculpturata
Gyroidina vicksburgensis
" sp
Eponides byramensis
" vicksburgensis
Rotalia byramensis
" dentata
" " var parva
Epistomina sp.
Mississippina monsouri
Siphonina advena
Siphoninella byramensis
Cancris sagra
Asterigerina bracteata
" subacuta
Pulvinulinella sp.
Cassidulina crassa
Cassidulinoides sp.
Globigerina bulloides
" sp.
Anomalina bilateralis
" cf grosserugosa
Planulina byramensis
Cibicides americanus
" lobatulus
" mexicana
" mississippiensis
" pseudoungerianus
" vicksburgensis
" sp
Planorbulinella larvata
Gypsina rubra
Lepidocyclina

ably complete. As can be seen from a study of it, a very large proportion of the *Foraminifera* range continuously or sporadically through the strata exposed at Vicksburg. Many of the most common species belong to this class; for example, *Textularia tumidula, Clavulina byramensis, Anomalina bilateralis, Bolivina caelata, Loxostoma amygdalaeformis, Cibicides pseudoungerianus, Bifarina vicksburgensis, Lenticulina vicksburgensis*, etc. The same is true of a large proportion of the *Miliolidae*, and of many other species of the *Lagenidae*.

The Byram marl, the most fossiliferous of the Vicksburg formations, contains certain species which appear to be confined within it. *Camerina* sp., one of the largest and most easily recognizable of the Byram *Foraminifera*, was not found in the lower formations. *Miliolidae* are very well developed, and several distinctive species, such as *Spiroloculina byramensis, Hauerina fragillissima*, and *Triloculina mississippiensis*, appear restricted to it. With the exception of a single specimen of *Peneroplis* in the Glendon (?), the genera *Peneroplis* and *Spirolina*, hitherto unknown to the Vicksburg, were observed only in the Byram. These two genera are of particular interest in demonstrating the similarity of Byram conditions of deposition to those which prevailed in the lower Miocene.

The Glendon (?) apparently has no outstanding *Foraminifera* which are characteristic. Like the type Marianna, the Marianna (?) at Vicksburg shows a marked development of comparatively large *Foraminifera* belonging to the *Lagenidae*, for example, *Lenticulina crassa, L. propinqua, Nodosaria obliqua, N. vertebralis*, and *Saracenaria italica*.

The Mint Spring is distinguished mainly by the absence or comparative rarity of many species common in the overlying strata, which may be attributed to unfavorable conditions. With the possible exception of *Nonionella pauciloba*, none of those present seems to be diagnostic.

In connection with characteristic Vicksburg *Foraminifera*, it is perhaps worth while to note that several specimens referred to *Textularia tumidula* on the check list show considerable resemblance to *Textularia warreni* of the Texas subsurface Vicksburg, being comparatively flat, having raised sutures, and including in their tests occasional grains of a dark mineral. The writers are inclined to believe that between *Textularia tumidula* and *T. warreni* there exists a relationship similar to that between *Textularia hockleyensis* and *T. distortio*, a relationship possibly of ecologic significance.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 11 (NOVEMBER, 1935), PP. 1668-1677, 1 FIG.

STRATIGRAPHY OF PENNSYLVANIAN HERMOSA FORMATION IN ELK MOUNTAINS, GUNNISON COUNTY, COLORADO[1]

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ABSTRACT

The Hermosa (Pennsylvanian) formation is well exposed in a number of places in the Elk Mountains in central Colorado. The three sections described in this paper are composed of sandstone, limestone, shale, and rocks of all intermediate compositions. Local and abrupt variations in composition and appearance are characteristic of the Hermosa, which, as a whole, is a distinct and easily recognizable stratigraphic unit. The Hermosa sections in the Elk Mountains are correlated with the Weber formation in areas on the east and south, and they resemble the Hermosa formation in the San Juan Mountains on the southwest.

The trend of lithologic changes suggests that the materials composing the Hermosa in the Elk Mountains were derived from an eastern highland or highlands.

INTRODUCTION

This paper describes certain sections of the Pennsylvanian Hermosa formation and calls attention to an area in which further interesting and possibly critical information regarding the Hermosa can be obtained. The area is in the heart of the Elk Mountains, Gunnison County, Colorado, and is of particular interest because of its intermediate geographic position between the Colorado River on the north and the Gunnison River on the south, where the Pennsylvanian has been described and called the "Weber formation."

Hayden[3] studied the Elk Mountains and assigned Holmes[4] to make a further study of their structural features, but reference must be made to Eldridge's work[5] for a description of the sedimentary formations. Eldridge mapped the Crested Butte Quadrangle, which includes Copper Creek, in the southern part of the Elk Mountains,

[1] Manuscript received, July 30, 1935. Published with permission of the director, United States Geological Survey.

[2] United States Geological Survey.

[3] F. V. Hayden, "Geology of Elk Mountains," *U. S. Geol. and Geog. Survey Terr. 7th Ann. Rept.* (1874), pp. 58–69.

[4] W. H. Holmes, "Report on the Geology of the Northwest Part of the Elk Range," *U. S. Geol. and Geog. Survey Terr. 8th Ann. Rept.* (1876), pp. 59–72.

[5] G. H. Eldridge, *U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte Folio No. 9* (1894), p. 6.

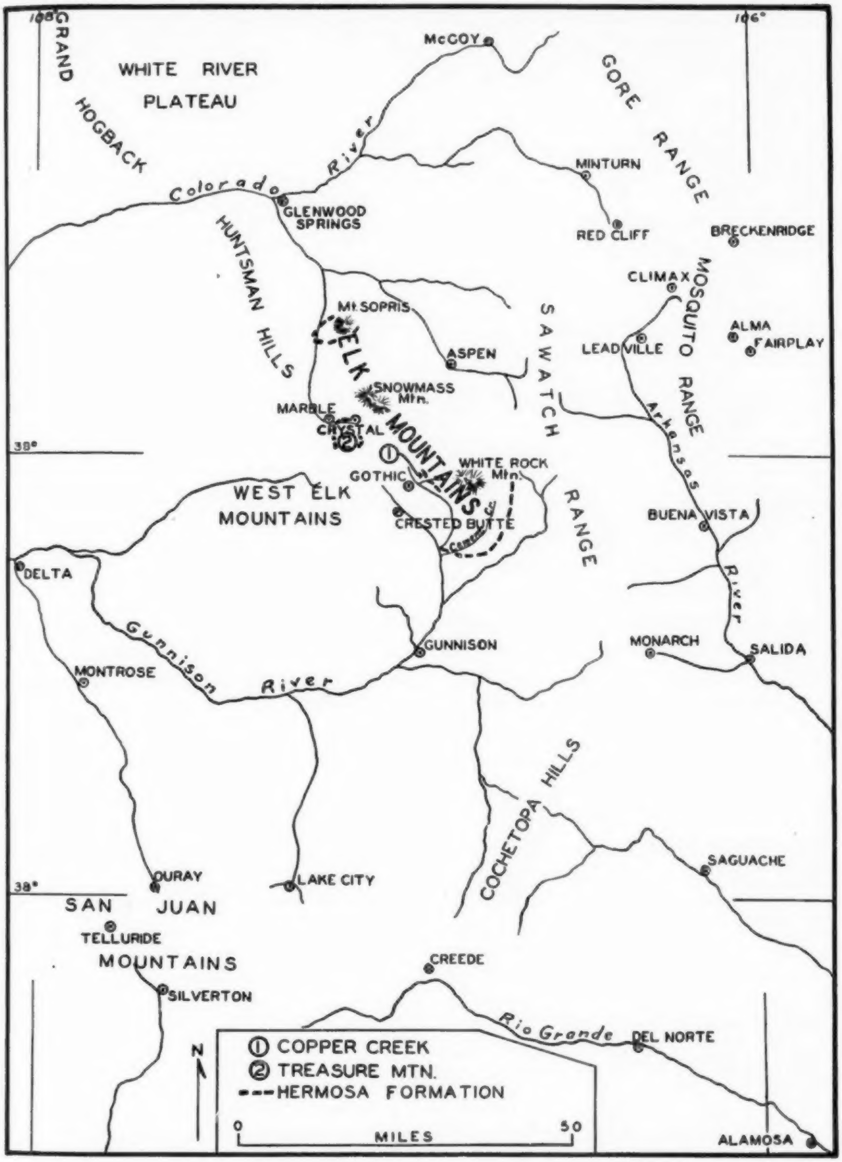

FIG. 1.—Index map showing location of Elk Mountains.

where one of the sections of the Hermosa given herein was measured. A detailed geologic study of the Snowmass Mountain area, also known as the Rock Creek or Crystal River mining district, was made by the writer[6] during the summers of 1930, 1931, and part of 1932. In the course of this work the Hermosa sections here described were studied. The work was done under the auspices of the Geological Survey in coöperation with the State of Colorado. The writer gratefully acknowledges the benefit and encouragement derived from numerous discussions with Wilbur S. Burbank regarding the stratigraphy of the Pennsylvanian of central Colorado.

The extent of the Elk Mountains and the location of the Hermosa outcrops in them are shown in Figure 1. The area is reached by railroad by way of Glenwood Springs to Marble or by way of Gunnison to Crested Butte. Entrance by automobile is more convenient, and in general the road information given on ordinary highway maps is reliable.

GENERAL GEOLOGY

Pre-Cambrian granite and gneiss are exposed at Cement Creek and in considerable areas on the southeast, and gneiss crops out in a very small area on Treasure Mountain.

The Cambrian, Ordovician, Devonian, and Mississippian beds occur in their normal development on Treasure Mountain and Cement Creek, as described by Vanderwilt and Fuller.[7] The Pennsylvanian and Permian are also present in these two areas. The Permian grits are the well known red feldspathic sandstones and conglomerates, more than 5,000 feet thick on the eastern flanks of the Elk Mountains, where, however, neither their base nor their top is found. An angular unconformity at the base of the Jurassic (Entrada sandstone) makes it doubtful whether all of the Permian is represented, particularly on the west side of the Elk Mountains. The principal exposures of the Hermosa formation in the Elk Mountains are shown in Figure 1. Around Mount Sopris the Hermosa beds are crushed and broken, and they are mixed with gypsiferous beds that normally overlie the Hermosa formation, which makes the area unfavorable for study.[8]

[6] J. W. Vanderwilt, "General Geology and Mineralization of the Snowmass Mountain Area, Gunnison County, Colorado, U. S. Geol. Survey (report in preparation).

[7] J. W. Vanderwilt and H. C. Fuller, "Correlation of Colorado Yule Marble and Other Early Paleozoic Formations on Yule Creek, Gunnison County, Colorado" (in preparation).

[8] Highly distorted gypsiferous rocks occur in several localities in the general region of southwestern Colorado and adjoining areas in Utah. In places the gypsum crops out well above its normal stratigraphic position. Such occurrences may or may not show

The sections at the south end of the Elk Mountains have not been described in detail. Those on Treasure Mountain and on Copper Creek are described in this paper.

The Jurassic Entrada sandstone and Morrison formation are well exposed on Treasure Mountain, on Copper Creek, and on the northwest end of Mount Sopris. The Morrison shales are conspicuous because of their characteristic variegated color, and the Entrada sandstone is everywhere present, though less than 40 feet thick.

The Dakota (?) quartzite, Benton shale, and Niobrara limestone, of Cretaceous age, are present in the Elk Mountains proper but are limited to the southwestern flanks. Younger members of the Cretaceous are found in the West Elk Mountains, where the nearest Tertiary formations also occur.

The Elk Mountains are the topographic expression of a large fault—the Elk Mountain fault—and three stocks of granodiorite aligned along it. The fault dips steeply toward the northeast and has Permian grits on the northeast side lying above overturned Jurassic (Morrison) and Cretaceous (Mancos) beds on the southwest side. To the northwest the fault becomes the monoclinal fold expressed in the Huntsman Hills and the Grand Hogback. White Rock Mountain, Snowmass Mountain, and Mount Sopris mark the three stocks of granodiorite. These and other peaks carved out of Permian grits form the very rugged crest of the range. An angular unconformity at the base of the Jurassic cuts out all the Paleozoic beds at a short distance west and southwest of the Elk Mountains and accounts for the scattered and erratic distribution of the Hermosa outcrops (Fig. 1).

HERMOSA SECTIONS ON TREASURE MOUNTAIN

The two sections of the Hermosa on Treasure Mountain are exceptionally well exposed, because the shaly content has been indurated to hornfels by metamorphism, which has also changed limestone to marble and sandstone to quartzite, so that the advantage of good outcrops is partly offset by the loss of most of the original lithologic features. The two sections are less than two miles apart (Fig. 1).

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an apparent relation to local or regional structure, and they have been explained by flowage of the gypsum similar to that of salt in salt domes. Much gypsum is exposed in the vicinity of the junction of Crystal River and Roaring Fork River, a few miles west of Mount Sopris. This area and Mount Sopris are along a regional zone of folding and faulting which could have affected the flowage, if any, of the gypsum. Around Mount Sopris the effect of intrusive activity may also have been important.

A. HERMOSA FORMATION AT WEST END OF TREASURE MOUNTAIN

		Feet
14.	Quartzite, gray, fine-grained; some beds shaly	79
13.	Conglomerate, marbleized limestone, and a few quartz pebbles in matrix of sandy limestone	45
12.	Quartzite, gray, shaly, and much altered	12
11.	Conglomerate, marbleized limestone, and a few quartz pebbles in matrix of sandy limestone	12
10.	Shaly quartzite, sandy hornfels, and a little limestone, much altered	162
9.	Conglomerate; white limestone marble pebbles 1–3 inches across in light gray limestone marble matrix	68
8.	Sandy hornfels containing much specularite and epidote, and some tourmaline, pyrite, and chlorite(?)	30
7.	Conglomerate; white limestone marble pebbles 1–3 inches in light gray limestone marble matrix	45
6.	Gray-to-greenish gray hornfels and shaly quartzitic sandstone. Shows much epidote, some garnet, and much specularite along joints	280
5.	Gray-to-black marbleized limestone with interbedded fine-grained sandstone and some shale. Some limestone is sandy or shaly, with some mica. Much epidote has formed in these beds both along bedding planes and along joints	260
4.	Gray hornfels, sandy in places, with alternating beds of gray and white marbleized limestone	76
3.	Dark gray fine-grained quartzite, sandstone, and a little interbedded hornfels	33
2.	White and gray limestone, well marbleized, mostly massive, with a few thin beds in part replaced by yellow serpentine	102
1.	Gray, green, and black hornfelsic quartzite with much garnet and epidote. Upper half contains alternating beds of recrystallized limestone. Locally conglomeratic with angular fragments of chert and quartzite	24
		1,228

B. HERMOSA FORMATION AT EAST END OF TREASURE MOUNTAIN, MEASURED ON EAST FACE OF WHITEHOUSE MOUNTAIN

		Feet
12.	Gray marbleized limestone and quartzite interbedded with and overlain by Jurassic (Morrison) quartzite	19
11.	Conglomerate, 1–3 inches of granite and gneiss pebbles, chert, and red clay in sandy matrix	14
10.	Gray sandy hornfels grading upward into shaly and quartzitic sandstone. All sand is fine-grained	115
9.	Gray-to-white marbleized limestone, thin-bedded, with bedding planes irregular and wavy. Some lower beds are fossiliferous, showing cross sections of cup corals, brachiopods, or pelecypods, and some crinoid stems, which are very difficult to collect. Upper 20 feet shaly. Near top or in lower part of overlying stratum, *Chaetetes milleporaceus* and *Amplexus?*, identified by G. H. Girty as Pennsylvanian, were collected	180
8.	Sandstone and shale like bed 6. Upper 30 feet grades upward into gray marbleized limestone	100
7.	Conglomerate; marbleized limestone pebbles averaging 1–2 inches across in matrix of medium-grained sandstone	12
6.	Medium-to-fine-grained gray quartzite in beds 10–20 feet thick, interbedded with hornfels of equal thickness	122
5.	Gray, fine-grained quartzite in well developed beds 6 inches to 4 feet thick, with the average 12–18 inches. Lower 45 feet is calcareous and shows some cross-bedding	235
4.	Gray marbleized limestone with irregular beds of quartzite or shaly sandstone up to 6 inches thick, which constitutes 15–25 per cent of the beds. Quartzite is fine-grained and calcareous. Contains following fossils: V. S. 160, 0–1, 65 feet above base, *Solenomya radiata*, *Solenomya anodontoides*, *Clinopistha radiata* var. *levis*, *Cardiomorpha missouriensis*, *Aviculipecten*	

rectilaterarius, Pseudorthoceras knoxense; V. S. 160, 0–2,—about 20 feet below top, *Spirorbis*	130
3. Gray hornfels, interbedded with 10–20 per cent limestone in lower half and 50 per cent in upper half	161
2. Gray marbleized limestone, thin-bedded; contains 5–10 per cent of interbedded quartzite and hornfels. In upper 40 feet sandstone and shale increase to about 50 per cent of rock	208
1. Conglomerate; angular blocks of chert and quartzite 1–2 inches across in matrix of dense black hornfelsic quartzite	2–20
	1,298

G. H. Girty identified the fossils and in a personal communication made the following statement concerning them.

The fauna of the siliceous shale (V.S. 161 0–1) is of a character most disadvantageous for age determination, for the fossils are none too well preserved and represent only pelecypod types, many of which can be identified even generically only upon characters that are not very trustworthy. This is more true of the fauna under consideration than of most pelecypod faunas, for it has been necessary to identify these fossils with types that are relatively little known. In spite of this fact I can hardly doubt that the age of this fauna is Pennsylvanian (possibly Pottsville). This interpretation is to some extent corroborated by the presence of the calcareous specimens (V.S. 161 0–2), especially by the one which contains so many shells of *Spirorbis* . . . for although we find *Spirorbis* in marine faunas, these minute worm tubes are especially abundant in rocks of nonmarine origin, where they are associated with plant remains indicating an environmental condition that is rare if not wholly unknown in our Mississippian rocks.

Concerning *Chaetetes milleporaceus*, Girty states:

It is so far as known confined to the Pennsylvanian, and it chiefly occurs in the earlier faunas of that period.

The Hermosa rests on the massive Mississippian (Leadville) limestone, but its upper boundary is somewhat arbitrary; the top is tentatively placed to include the highest persistent limestone of any consequence. Fine-grained nonfossiliferous sandstones and shales several hundred feet thick overlie the Hermosa and seem to grade into it and into Permian grits above. The differences in detail of the two Hermosa sections are largely attributable to lensing of strata, although some of the differences may be due to the more intense metamorphism of certain beds. The conglomerate at the base of the Hermosa is persistent throughout the area and is particularly well developed in the vicinity of the Colorado Yule marble quarry, above Marble, and on Whitehouse Mountain. It fills depressions 10–20 feet across and deep in the top of the Mississippian (Leadville) limestone, making an irregular contact. The conglomerate consists of angular to subrounded fragments, 12 inches across but averaging less than 3 inches, of chert and fine-grained quartzite in fine-grained, dense black matrix which

was originally shale or sandy shale. A similar conglomerate rests on the Mississippian (Leadville) limestone in mine workings under Aspen and Smuggler mountains, in the Aspen area.[9] Similar conglomerates occur at this horizon in the Gold Brick district[10] and in the Ouray area[11] (the base of the Molas), suggesting comparable conditions of deposition at the beginning of Pennsylvanian time in these widely separated areas.

The limestones, sandstones, and shales of the Hermosa formation commonly change by gradation both laterally and vertically from one into another, although well defined boundaries are usually present. Most of the limestones effervesce with cold dilute hydrochloric acid, but some seem to be dolomitic. Conglomerates 7, 9, and 13 of section A are unusual rocks that crop out in very conspicuous white bands which, when seen from a distance, resemble the Colorado Yule marble or Mississippian (Leadville) formation. They consist of well rounded pebbles of white marble in a gray-to-white marble matrix. They are not present at the east end of Treasure Mountain.

HERMOSA SECTION ON COPPER CREEK

The section on Copper Creek represents the upper part of the Hermosa formation, just below the typical grits of the Permian. An intrusive contact terminates the Hermosa below. The rocks are unaltered and relatively fossiliferous. Some fossils were collected, but further search would undoubtedly yield a more representative collection.

The scarcity of fossils on Treasure Mountain is somewhat compensated by their abundance on Copper Creek, which justifies the description of the incomplete Copper Creek section. The lower beds cut out by the granodiorite are without doubt the Weber shale on Cement Creek, described by Eldridge. The sandstones and limestones in the Copper Creek section are ordinary types, as described below.

HERMOSA FORMATION ON COPPER CREEK

	Feet
Permian grits, fine-to-coarse red sandstones with beds of conglomerate at irregular intervals	
Tentative boundary between Pennsylvanian and Permian	

[9] J. W. Vanderwilt, "Revision of Structure and Stratigraphy, and Its Bearing on the Ore Deposits of the Aspen District, Pitkin County, Colorado," *Econ. Geol.*, Vol. 30 (1935), p. 229.

[10] R. D. Crawford and P. G. Worcester, "Geology and Ore Deposits of the Gold Brick District, Colorado," *Colorado Geol. Survey Bull. 10* (1916), pp. 63–64.

[11] W. S. Burbank, "Revision of Geologic Structure and Stratigraphy in the Ouray District of Colorado, and Its Bearing on Ore Deposition," *Colorado Sci. Soc. Proc.*, Vol. 12, No. 6 (1930), pp. 161–62.

18.	Limestone, dark gray-to-black, very sandy, grading into sandstone below. Following fossils were collected (lots 7154 and 7154a): *Meekella striaticostata*, *Productus coloradoensis*, *Productus coloradoensis* var., *Productus cora*, *Pseudomonotis? sp.*, *Pharkidonotus percarinatus?*, *Bucanopsis?* sp., *Phanerotrema grayvillense*, *Goniospira?* sp., *Composita subtilita*	5
17.	Sandstone, gray, medium-grained, micaceous, massive	35
16.	Sandy shale, gray-to-black, micaceous, and calcareous	21
15.	Limestone, blue-gray, massive, nodular	5
14.	Sandstone, gray, medium-to-coarse-grained, grading into limestone above	19
13.	Calcareous sandstone similar to sandstone below except for calcareous content	75
12.	Sandstone, gray-to-brown, fine-grained. Lower part is massive, micaceous, and has characteristic chloritic green stain; upper part has thin and irregular bedding	153
11.	Sandy shale or shaly sandstone, brown-to-dark gray and black	69
10.	Calcareous sandstone, gray-to-light buff, well bedded, fine-grained and micaceous	51
9.	Conglomeratic sandstone, gray, with pebbles of sandstone, marble, and quartzite 1.5 inches across	6
8.	Calcareous sandstone, gray-to-light buff, micaceous, massive	13
7.	Limestone, gray, thick-bedded, sandy, micaceous	6
6.	Calcareous sandstone, gray-to-brown, fine-grained, thin-bedded, micaceous	59
5.	Sandstone, gray-to-brown, fine-grained, micaceous, massive	50
4.	Limestone, blue-gray, with thin and uneven bedding. Following fossils were collected in upper 10 feet (lot 7157): *Lophophyllum profundum*, *Crania* sp., *Derbya crassa*, *Productus coloradoensis*, *Productus* sp., *Marginifera?* sp. *Pugnoides osagensis* var., *Spirifer cameratus*, *Composita subtilita*, *Cleiothyridina pecosi*, *Hustedia mormoni?*	135
3.	Cross-bedded sandstone, reddish brown, with chloritic green stain. Lower part thin-bedded; upper part massive. Rock is fine-grained, micaceous, and composed of quartz	51
2.	Nodular limestone, gray, thin-bedded. Following fossils were collected in lower part (lot 7156): *Marginifera ingrata?*, *Composita subtilita*, *Cleiothyridina pecosi?*	24
1.	Sandstone, brownish gray, fine-grained, slightly micaceous, thick-bedded. Base is intrusive contact of granodiorite of White Rock Mountain	60
		837

The fossils listed in the section were identified by G. H. Girty, who in personal correspondence concerning them says:

> As to geologic age, though the paleontologic evidence afforded by some collections is very tenuous, I should refer all of them to Pennsylvanian time and to rocks which would correlate with the Hermosa formation. . . . None of the collections, on the other hand, has a Rico fauna. Several that contain one or two species, and those doubtfully identified or of negligible value, as evidence, might be Rico (or Permian) if other evidence demanded it, but in proportion as the faunas are extensive enough to have determinative value, they indicate Pennsylvanian age and a horizon that can be referred to one part or other of the Hermosa formation.

The Weber shale of Eldridge, cut out on Copper Creek by the granodiorite, is represented on Cement Creek by soil-covered slopes. However, the shales are fossiliferous, as indicated by the presence of well preserved silicified fossils in the soil. The following fossils, identified by G. H. Girty, were collected (lot 7155).

Lophophyllum profundum, *Echinochrinus* sp., *Crinoid* stems and plates, *Chonetes* aff. c. *granulifer*, *Chonetes* aff. c. *geinitzianus*, *Productus coloradoensis*, *Productus* aff. p. *pertenuis*, *Spirifer opimus*, *Spirifer* sp. *Spiriferina* aff. s. *subspinosa*, *Nucleospira*? n. sp. *Composita subtilita* var.

The fossils came from the slope about 250 feet above the Leadville (Mississippian) limestone and on the north side of Cement Creek 3 miles east of the Gunnison-Crested Butte highway.

CONCLUSIONS

The Hermosa sections in the Elk Mountains differ in detail even within horizontal distances of less than a mile; locally prominent beds lens out abruptly along the strike. In spite of these marked changes along the strike the general lithology of the Hermosa formation as a whole is characteristic. This statement also applies to the Pennsylvanian Weber formation in the areas east and south of the Elk Mountains, and inasmuch as the beds everywhere rest on or overlap the Mississippian limestone, it is reasonably certain that they represent the same stratigraphic horizon.

Certain trends of change in lithology are evident in these Pennsylvanian beds. In the Elk Mountains, the White River Plateau,[12] and the Aspen district[13] limestone is abundant. Farther northeast, at Red Cliff,[14] at McCoy,[15] and in the Mosquito Range,[16] sandstones and grits are abundant, as they are in the Bonanza,[17] Monarch[18] and Gold Brick[19] districts. In each of these areas, the Hermosa and Weber formations seem to grade into the overlying Permian, which has been a natural excuse for treating the Pennsylvanian and Permian together in paleogeographic discussions that postulate a southwestern source

[12] V. J. Hendrickson, personal communication.

[13] J. E. Spurr, "Geology of the Aspen Mining District, Colorado," *U. S. Geol. Survey Mon. 31* (1898), pp. 30–33.

[14] R. D. Crawford and Russell Gibson, "Geology and Ore Deposits of the Red Cliff District, Colorado," *Colorado Geol. Survey Bull. 30* (1925), pp. 38–39.

[15] T. S. Lovering and J. H. Johnson, "Meaning of Unconformities in Stratigraphy of Central Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 4 (1933), p. 368.

[16] S. F. Emmons, J. D. Irving, and G. F. Loughlin, "Geology and Ore Deposits of the Leadville Mining District, Colorado," *U. S. Geol. Survey Prof. Paper 148* (1927), p. 58.

[17] W. S. Burbank, "Geology and Ore Deposits of the Bonanza Mining District, Colorado," *U. S. Geol. Survey Prof. Paper 169* (1932), p. 13.

[18] R. D. Crawford, "Geology and Ore Deposits of the Monarch and Tomichi Districts, Colorado," *Colorado Geol. Survey Bull. 5* (1913), pp. 67–68.

[19] R. D. Crawford and P. G. Worcester, "Geology and Ore Deposits of the Gold Brick District, Colorado," *Colorado Geol. Survey Bull. 10* (1916), pp. 63–64.

(San Luis highland)[20] for the sedimentary material. Burbank[21] believes that this highland probably did not attain its maximum development until later Pennsylvanian or Permian time. In the areas referred to there is no evidence in the Hermosa and Weber formations of a southwestern highland, the trend of lithologic changes described strongly suggesting that the sedimentary materials were derived from an eastern highland or highlands.

[20] F. A. Melton, "The Ancestral Rocky Mountains of Colorado and New Mexico," *Jour. Geol.*, Vol. 33 (1925), pp. 84–88.
J. H. Johnson, "Contribution to the Geology of the Sangre de Cristo Mountains of Colorado," *Colorado Sci. Soc. Proc.*, Vol. 12 (1929), pp. 1–21.

[21] W. S. Burbank, "Relation of Paleozoic and Mesozoic Sedimentation to Cretaceous-Tertiary Igneous Activity and the Development of Tectonic Features in Colorado," *Am. Inst. Min. Met. Eng. Lindgren Volume* (1933), pp. 28–281.

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VOL. 19, NO. 11 (NOVEMBER, 1935), PP. 1678–1692, 1 FIG.

DOLOMITE IN PERMIAN LIMESTONES OF WEST TEXAS[1]

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ABSTRACT

This paper presents the results of a series of calcium and magnesium determinations made on well samples from the Permian limestones of West Texas. With the exception of some isolated areas, these limestones have a high magnesium content, and probably should be classified as dolomite limestones. No widespread relationship exists between magnesium content and the porosity of the limestone.

There is wide variation of opinion regarding the relative amounts of limestone and dolomite in the so-called "Big lime" of the Permian basin of West Texas. A few petrographic studies have been made, and some differentiation attempted on the basis of microscopic examination and rate of reaction with 10 per cent hydrochloric acid. Such "determinations" as the latter are, at best, mere approximations. Hence, a series of chemical analyses was started in order to clarify, if possible, some of the confusion and differences now existing.

In making this study on the basis of chemical analysis alone, it is realized that, while the relative percentage of calcium carbonate and magnesium carbonate are easily determined, the physical form in which these constituents exist in the original formation is not determined. True dolomite is a definite mineral composed of equi-molecular quantities of calcium and magnesium carbonate, or a weight ratio of 54.26 per cent $CaCO_3$ and 45.74 per cent $MgCO_3$. It is realized that very commonly impurities decrease these percentages and that in very few rocks is the exact 1 : 1 molecular ratio encountered in natural deposits.

The term "dolomite" is generally used to designate any limestone which contains appreciable quantities of magnesium carbonate, though such terminology is ambiguous. Concerning the nomenclature of dolomite and related deposits, Twenhofel says:[3]

[1] Manuscript received, August 3, 1935.

[2] Chemical engineer, University Lands, 805 San Angelo National Bank Building. Introduced by Hal P. Bybee.

[3] W. H. Twenhofel *et al.*, *Treatise on Sedimentation*, 1st ed. (1926), pp. 251–52. Williams and Wilkins, Baltimore, Maryland.

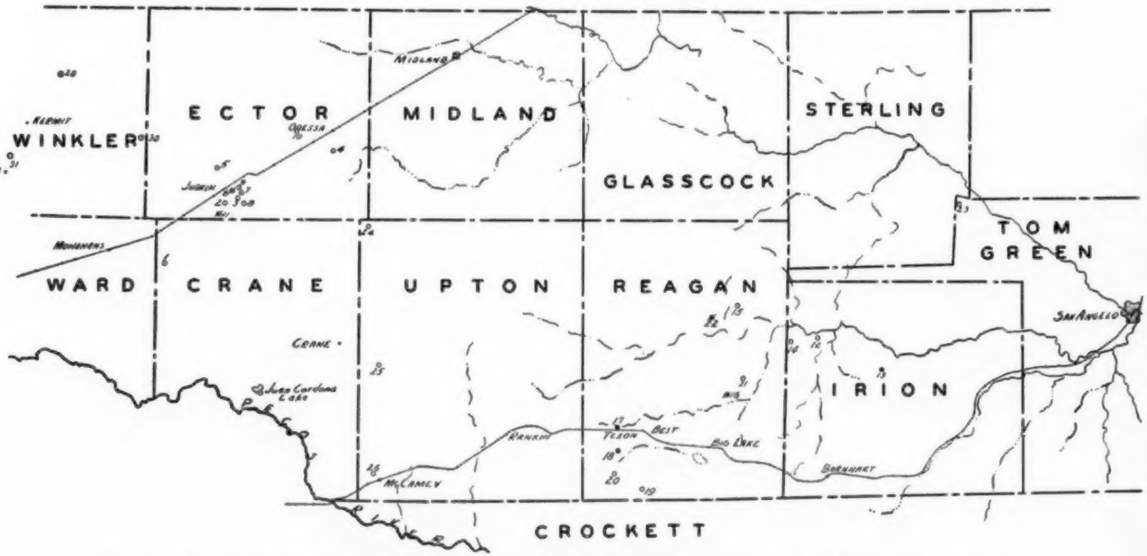

FIG. 1.—Map showing location of West Texas wells, samples from which were examined for dolomite content
Hollow circles: wells in which limestone section is predominantly dolomite limestone.
Solid circles: wells in which limestone section contains little or no dolomite.
Circles with diagonal line: wells showing decrease in dolomite content in porous horizons.

Dolomite limestones are those which are dominantly composed of dolomite. There are probably all gradations between calcite and dolomite limestones, but the occurrences are few in which the calcite and the dolomite occur in approximately equal proportions. Limestones which have less dolomite than justifies their assignment to dolomite limestones may be designated dolomitic limestones. Magnesium carbonate also exists in limestones in other forms than as dolomite, being either in solid solution in calcite or in isomorphous mixture therewith. Calcite is also miscible with dolomite, in each case the mineralogical properties of the mineral with which the mixing takes place not being affected. Limestones in which magnesium carbonate occurs not in the form of dolomite may be termed magnesium limestones.

Calcium and magnesium determinations have been made on lime samples from 35 wells. Approximately 150 analyses have been made, ranging from 1 to 18 samples from each well. All analyses were made by standard analytical methods.[4] In the absence of petrographic evidence to the contrary, and for the purpose of simplification, all magnesium found to be present in the limestones examined has been assumed to be in the form of the carbonate. Likewise, all magnesium carbonate has been assumed to be in the form of dolomite. The latter assumption is undoubtedly open to question, since the two carbonates may conceivably be present as a physical mixture of the two and not as the combined mineral.

The criterion for comparison used in this study is the molecular ratio of calcium carbonate to magnesium carbonate. This is the ratio obtained when the weight percentages of the two compounds are divided by their respective molecular weights. For example, pure dolomite is composed of 54.26 per cent calcium carbonate and 45.74 per cent magnesium carbonate, by weight. Since the molecular weights of these two compounds are, respectively, 100 and 84.3, the molecular ratio is $\frac{54.26}{100}:\frac{45.74}{84.3}::1:1$.

Actual dolomite percentage is easily calculated by dividing the percentage of magnesium carbonate in the sample by 45.74. However, this datum is not reliable as a basis of comparison because it is affected by the presence of impurities such as sand, pyrite, and shale in the sample. The use of the molecular ratio eliminates any error from this source since only acid-soluble constituents are considered.

In Table I are listed the data from the most important wells examined.

[4] F. P. Treadwell and W. T. Hall, *Qualitative Analysis*, Vol. II, 6th ed. (1924), p. 87.

TABLE I*

Interval in Feet (Depth)	Per Cent $CaCO_3$	Per Cent $MgCO_3$	Molecular Ratio $\frac{CaCO_3}{MgCO_3}$	Per Cent Dolomite	Description and Remarks
CRANE COUNTY					
1. Gulf, Edwards 1-D. Public School Land, Block 18, Section 21, 330 feet from S. and E. lines. Elevation 2,657 feet. Top Blaine limestone, about 2,910 feet					
2,885–90	49.8	31.0	1.35	68	Brown, Whitehorse
3,070–75	52.3	32.4	1.36	71	Light gray, crystalline, some calcite
3,352–62	50.2	36.4	1.16	80	Dark gray, some black shale
3,500–10	55.8	37.0	1.27	81	Gray, granular, crystalline. 1 boiler of water per hour at 3,500–10 feet
3,950–57	55.4	37.8	1.23	83	Soft, white
4,250–52	51.8	41.5	1.05	91	White
4,576–81	51.2	39.5	1.09	86	Dark gray, oil-stained
ECTOR COUNTY					
2. J. S. Cosden, Connell 1-A. Public School Land, Block B-16, Section 13, 1,320 feet from N. and E. lines. Elevation, 2,847 feet. Top Blaine limestone, 3,200 feet					
3,200–02	51.3	38.6	1.12	84	Light gray
3,248–55	51.9	40.0	1.10	88	Light gray
3,290–95	46.3	37.6	1.04	82	Light gray; some gray sand and shale
3,330–38	51.1	40.8	1.05	89	Light gray; considerable pyrite
3,360–69	53.1	42.3	1.06	93	Light gray, hard
3,402–09	49.1	38.6	1.07	84	Cream-colored dolomite, soft
3,443–50	32.9	26.4	1.05	58	Dark gray-brown, sandy, oil-stained; top of pay 3,436 feet
3,495–98	52.3	42.4	1.04	93	Medium gray
3,547–50	56.2	39.2	1.21	86	Mottled gray-brown, some pyrite; oil-stained; some quartz
3,598–3,603	54.1	37.3	1.22	82	Dark gray
3,648–53	47.8	38.5	1.24	84	Medium gray
3,703–08	55.3	38.2	1.22	84	Light gray
3,750–56	55.9	39.7	1.18	87	Very light gray
3,798–3,805	58.1	36.0	1.36	79	Light gray
3,855–68	52.8	38.2	1.16	84	Medium gray
3,892–99	54.0	41.1	1.11	90	Medium gray-brown
3,925–40	56.9	42.6	1.13	93	Light gray-tan
3,975–87	54.5	42.3	1.09	93	Fine light gray
3. Cosden, University 1-B. University Land, Block 35, Section 2, 1,650 feet from N. and 440 feet from E. lines. Elevation, 2,890 feet. Top Blaine limestone, 3,260 feet					
3,120–30	54.9	31.6	1.46	69	Brown; some anhydrite, Whitehorse
3,304–12	52.5	39.0	1.13	85	Very light gray
3,575–80	54.9	43.9	1.05	96	Very light brown; oil-soaked
4. Davis, Hendrick 1. T. & P., T. 2 S., Block 42, Section 46, Center of SW. ¼. Elevation, 2,878 feet. Top Blaine limestone, 4,665 feet					
4,565–83	47.2	26.6	1.50	58	Brown, crystalline; considerable sand
4,700–10	38.1	32.4	0.99	69	Medium gray, sandy, some pyrite
4,825–35	54.7	42.5	1.08	93	Gray-brown
5. Duffey *et al.*, Rutledge 1. Public School Land, Block B-15, Section 7, 990 feet from S. and 330 from E. lines. Elevation, 2,967 feet. Top Blaine limestone, 3,590 feet					
3,630–50	53.3	35.2	1.28	77	Medium gray; crystalline; some calcite
3,740–50	51.8	24.3	1.8	53	Medium gray; much calcite
3,895–3,910	51.9	41.7	1.05	91	Light gray, compact; some pyrite
4,140–60	56.0	38.5	1.23	84	Brown, crystalline ("sugary"), some calcite

* Unless otherwise stated, all samples examined and listed are Blaine in age. Serial numbers at left preceding names of wells correspond with locations in Figure 1.

TABLE I (*Continued*)

Interval in Feet (Depth)	*Per Cent $CaCO_3$*	*Per cent $MgCO_3$*	*Molecular Ratio $\frac{CaCO_3}{MgCO_3}$*	*Per Cent Dolomite*	*Description and Remarks*
6. Gulf, Connell 1-B. Public School Land, Block B-16, Section 1, 440 feet from E. and 2,310 feet from N. lines. Elevation, 2,898 feet. Top Blaine limestone, 3,160 feet					
3,340–50	47.4	32.9	1.22	72	Light gray, sandy
3,480–90	81.6	18.7	3.68	41	Brown; oil-stained (showing oil and gas 3,482 feet)
3,695–3,700	67.2	36.4	1.55	80	Dark gray, oil-soaked
7. Penn *et al.*, Kloh 1. T. & P., T. 3 S., Block 44, Section 7, 330 feet from S. and 2,310 feet from E. lines. Elevation, 2,925 feet. Top Blaine limestone, 3,410 feet					
3,255–75	57.8	20.3	2.40	44	Brown; some anhydrite, considerable SiO_2, Whitehorse
3,425–40	53.2	37.9	1.18	83	Light brown and gray; some SiO_2; showing gas
3,455–70	51.2	40.7	1.06	89	Very light gray; some SiO_2
3,500–15	54.4	37.9	1.20	83	Brown; some SiO_2
3,570–85	49.9	37.7	1.12	83	Mixed light gray and light brown
3,680–90	50.9	38.8	1.10	85	White
3,725–30	56.3	41.2	1.15	90	Brown, very hard; some pyrite and some calcite; top of pay 3,720 feet
8. Penn-Llano *et al.*, Hogen 1. T. & P., T. 3 S., Block 44, Section 18, 330 feet from N. and W. lines. Elevation, 2,914 feet. Top Blaine limestone, 3,485 feet					
3,420–35	52.4	32.2	1.37	70	Brown limestone; little anhydrite; Whitehorse
3,520–30	50.7	36.9	1.16	81	Dark gray
3,625–35	51.7	37.8	1.15	83	Medium gray; some calcite
3,830–40	53.2	41.0	1.10	90	Fine white, crystalline; hole full sulphur water at 3,832–41 feet
9. Simms-Phillips, University A-1. University Land, Block 35, Section 1, 2,970 feet from N. and 440 feet from E. lines. Elevation, 2,915 feet. Top Blaine limestone, 3,290 feet					
3,318–27	54.8	29.9	1.54	65	Medium gray
3,442–50	51.2	38.9	1.11	85	Gray
3,605–11	55.9	43.9	1.07	96	Gray
10. Stanolind, Cowden 1. T. & P., T. 2 S., Block 43, Section 26, 330 feet from S. and 1,320 feet from W. lines. Elevation, 2,942 feet					
3,935–45	53.4	42.5	1.06	93	Core, medium gray
11. Texas, Cosden-Connell 5. Public School Land, Block B-16, Section 24, 330 feet from S. and E. lines. Elevation, 2,843 feet. Top Blaine limestone, 3,382 feet					
3,400–08	52.7	29.8	1.49	65	Mixed light and dark gray; some calcite
3,415–18	50.9	35.2	1.22	72	Brown
3,550–55	49.4	36.4	1.14	80	Light gray; some pyrite
3,654–60	53.4	37.2	1.21	81	Dark gray
3,871–78	53.6	38.3	1.18	84	Dark brown, crystalline; oil-soaked; some calcite
3,993–4,004	69.1	24.4	2.38	53	Light brown, crystalline; some calcite; hole full sulphur water
IRION COUNTY					
12. Beasley *et al.*, Sawyer 1. H. & T. C., Block 24, Section 3032. Top Blaine limestone 1,530 (?) feet					
1,610–20	60.8	13.5	3.8	30	Light gray; crystalline
1,784–88	48.3	33.7	1.21	74	Mixed brown and gray; oil-stained, soft
13. Benedum and Trees, Sugg 1. H. & T. C., Block 28, Section 3081, 1,560 feet from S. and 925 feet from W. lines. Elevation, 2,376 feet. Top Blaine limestone, 1,165 feet					

TABLE I (*Continued*)

Interval in Feet (Depth)	*Per Cent $CaCO_3$*	*Per Cent $MgCO_3$*	*Molecular Ratio $\frac{CaCO_3}{MgCO_3}$*	*Per Cent Dolomite*	*Description and Remarks*
1,630–40	47.9	37.4	1.08	81	Brown, very crystalline; some quartz and some sandy shale
1,725–45	82.9	Trace			Medium and light gray; some calcite and pyrite
1,900–10	95.5	None			Light gray; crystalline
1,990–2,000	89.0	None			Light and dark gray; crystalline, much calcite
14. Kirby *et al.*, Sawyer 1. H. & T. C., Block 24, Section 3047, 150 feet from center of W. line. Elevation, 2,525 feet. Top Blaine limestone, 1,815 feet					
1,988–2,000	44.7	33.2	1.13	73	Light gray; some gray shale and pyrite; sandy
2,108–19	54.7	40.0	1.15	88	Hard, white, much calcite; showing oil
2,240–48	54.4	43.4	1.06	95	Medium gray; oölitic; water
2,290–95	55.6	34.1	1.38	75	White, crystalline
2,314–20	56.0	33.4	1.41	73	Dark cream-brown
2,402–07	55.4	38.5	1.21	84	Dirty white; very crystalline
2,500–07	53.5	35.4	1.31	77	Dark gray, mottled crystalline
2,593–2,605	41.5	31.8	1.10	70	Dark gray; crystalline, some sand, shale, and pyrite
REAGAN COUNTY					
15. Amerada *et al.*, Sawyer 1. T. & P., Block 1, Section 125, 990 feet from E. and 330 feet from S. lines. Elevation, 2,527 feet. Top of Blaine limestone, 2,350 feet					
2,365–70	55.9	31.2	1.51	68	Light gray; oil-soaked; showing gas, 2,380 feet
2,650–60	58.6	31.4	1.57	89	White, crystalline
2,825–40	48.6	36.2	1.13	79	Very light gray; crystalline; hole full salt water, 2,850 feet
16. Beasley, Sawyer 1. Robinson Survey, Section 8, 1,320 feet from N. and 3,960 feet from E. lines. Elevation, 2,586 feet. Top Blaine limestone, 2,240 feet					
2,250–60	53.4	31.8	1.41	70	Cream-colored
2,373–85	48.0	33.1	1.22	72	Hard smoky gray, some SiO_2
2,475–83	57.5	31.1	1.56	68	Medium gray, crystalline; some shale; oil, 2,479 feet
2,493–97	49.7	37.8	1.11	83	Soft, dirty white
2,615–20	49.2	39.1	1.06	85	White; some pyrite
2,678–80	47.7	34.8	1.16	76	Cream-colored
2,810–20	42.9	32.3	1.12	71	Medium gray, crystalline; 500 feet sulphur water at 2,815–20 feet
17. Big Lake Oil Company, University 179. University Land, Block 2, Section 10, 660 feet from S. and E. lines. Elevation, 2,690 feet. Top Blaine limestone, 2,980 feet					
3,003–07	51.9	28.0	1.56	61	Dark gray and brown, crystalline
3,052–54	87.5	8.3	8.9	19	White, crystalline
3,105–09	89.4	Est. 3–5			Light gray
3,163–68	80.5	Trace			White, crystalline
3,208–13	91.8	Trace			Hard, white, crystalline; porous; showing gas, 3,213 feet
3,238–48	92.5	Trace			Light gray, crystalline; oil-soaked
3,290–3,303	92.4	Trace			Gray, crystalline; porous; some SiO_2; 1,800 feet salt water, 3,305 feet
3,385–93	94.8	Trace			Medium gray; honey-combed; some SiO_2
3,495–3,503	94.7				Medium gray
18. California, University 1. University Land, Block 8, Section 13, 330 feet from N. and 2,310 feet from E. lines. Elevation, 2,861 feet. Top Blaine limestone, 3,215 feet					

TABLE I (*Continued*)

Interval in Feet (Depth)	*Per Cent $CaCO_3$*	*Per Cent $MgCO_3$*	*Molecular Ratio $\frac{CaCO_3}{MgCO_3}$*	*Per Cent Dolomite*	*Description and Remarks*
3,215–20	50.2	33.1	1.28	72	Medium gray
3,415–22	79.4	Trace			Light gray-to-white
19. California, University 3. University Land, Block 7, Section 14, 2,328 feet from N. and 2,310 feet from W. lines. Elevation, 2,821 feet. Top Blaine limestone, 2,980 feet					
2,980–90	22.4	14.3	1.33	31	Light gray, granular, very crystalline, sandy; much SiO_2
3,075–82	43.3	33.8	1.08	74	Medium gray; "sugary" crystalline
20. Gulf-State, Campbell 1. University Land, Block 1, Section 1, 330 feet from N. and W. lines. Elevation, 2,911 feet. Top Blaine limestone, 3,165 feet.					
3,240–50	34.0	22.9	1.25	50	Medium gray; crystalline, sandy
21. Humble-Dunning, Bar S Ranch 1. T. & P., Block 1, Section 93, 660 feet from S. and E. lines. Elevation, 2,480 feet. Top Blaine limestone, 2,110 feet					
2,200–10	50.1	29.8	1.42	65	Brown, some calcite
2,296–2,300	51.6	37.6	1.16	82	Hard, medium gray
22. Simms, Sawyer Cattle Co. 1. C. A. Glass Survey, Block 1, Section 12, 150 feet from S. and 1,250 feet from W. lines. Elevation, 2,570 feet. Top Blaine limestone, 2,465 feet					
2,558–70	40.3	19.9	1.71	44	Medium gray; considerable SiO_2
2,670–77	51.3	36.8	1.17	81	Medium gray
2,855–58	51.0	39.4	1.09	86	Hard, medium gray; crystalline
2,975–81	48.6	37.2	1.1	81	Cream-colored; some pyrite
3,056–68	91.2	Trace			Dark gray; crystalline; porous; hole full water at 3,060 feet
3,110–17	61.8	32.2	1.62	71	Dark gray, crystalline
3,193–99	86.2	Est. 3–5			Light gray; semi-porous; hole full salt water at 3,195 feet
3,248–99	85.0	Trace			Light gray
3,366–70	41.6	Trace			Dark gray; some pyrite; much SiO_2
TOM GREEN COUNTY					
23. Roxana, Clark 1. G. C. & S. F., Block A, Section 5, 330 feet from N. and 1,320 feet from W. lines. Elevation, 2,224 feet. Top Blaine, 710 (?) feet. Top Clearfork, 1,340 feet					
1,345–50	50.0	37.6	1.12	82	Medium gray to cream-colored, sandy, some pyrite; showing oil at 1,355 feet
1,535	50.1	39.1	1.08	86	Medium gray; some quartz
1,650	52.5	40.6	1.09	89	Medium gray; some quartz
1,930	48.4	37.2	1.10	81	Medium gray; some shale
2,095	51.5	40.1	1.08	88	Brown, crystalline
2,250	53.2	38.8	1.16	85	Gray, cream-colored, crystalline, soft
2,450	49.4	36.6	1.14	80	Light gray; some calcite and pyrite; hole full water at 2,470 feet
2,600	50.8	40.4	1.06	88	Gray and brown; some gray shale; hard
2,765	51.2	40.6	1.06	89	Light gray
2,845	55.0	42.6	1.09	93	Very light gray; crystalline; soft, hole full water at 2,835 feet
2,950–55	55.9	41.8	1.13	92	Medium gray; much calcite
3,050–52	54.6	43.6	1.06	95	Very light gray, sandy
UPTON COUNTY					
24. Broderick and Calvert, Homer National Bank 1. T. & P., T. 4 S., Block 42, Section 22. Elevation, 2,890 feet. Top Blaine limestone, 4,710 feet					
4,720–26	70.9	24.5	2.44	54	White, some calcite
4,819–23	53.1	34.8	1.29	76	Light gray

TABLE I (*Continued*)

Interval in Feet (Depth)	*Per Cent $CaCO_3$*	*Per Cent $MgCO_3$*	*Molecular Ratio $\frac{CaCO_3}{MgCO_3}$*	*Per Cent Dolomite*	*Description and Remarks*
25. Humble, Damron 1. G. C. S. D. & R. G. N. G., Block F, Section 192, 330 feet from N. and W. lines. Elevation, 2,756 feet. Top Blaine limestone, 2,870 feet					
2,949–57	48.2	28.7	1.42	63	White, some calcite and pyrite
2,968–77	54.3	31.5	1.45	69	Cream-colored "grainy" calcite and pyrite
3,065–70	54.7	32.4	1.42	71	Dark cream, crystalline; some calcite, soft
3,100–10	55.0	35.2	1.32	77	Brown, oil-stained, soft
3,250–55	55.9	32.0	1.47	70	White, crystalline, soft
3,320–35	52.9	38.2	1.17	84	Mixed white and dark gray, very hard
26. Marland, Burleson 3. T. C. Jones Survey, Section 100. Elevation, 2,595 feet. Top Blaine limestone, 2,030 feet					
2,070–85	33.9	23.7	1.86	52	Gray
2,111–13	53.5	42.2	1.07	92	Gray, porous; good showing oil
2,210–15	56.4	30.7	1.55	67	Gray and brown, porous; oil, 2,235–50 feet
2,260–65	71.4	29.2	2.06	64	Gray and brown, porous
2,300–08	55.7	38.7	1.21	85	Gray and white; some calcite; flowing by heads at 2,298 feet
2,360–70	55.9	39.7	1.19	87	Gray, porous, oil-stained
2,510–20	55.4	38.6	1.21	85	Gray, tight; some calcite
2,705–15	56.9	36.5	1.31	80	Gray, considerable calcite; soft
2,960–70	57.5	40.9	1.18	90	Light gray
3,120–30	54.8	43.9	1.05	96	Brown, porous
3,320–30	54.3	42.3	1.08	93	Gray and brown
3,455–65	54.3	42.1	1.08	92	Brown
3,640–45	50.1	43.5	1.04	95	Medium gray
3,920–25	70.2	18.8	3.14	41	Medium gray; much calcite
4,040–45	84.0	12.7	5.6	28	Brown and gray; some calcite
4,160–70	55.3	41.4	1.13	91	Brown and gray; much calcite
4,490–4,506	52.6	41.4	1.07	91	Dark gray; hole full sulphur water at 4,500 feet
WARD COUNTY					
27. Rector, Monroe 1. H. & T. C., Block 33, Section 62, 660 feet from SW. and SE. lines.					
4,654	81.5	Est. 5			Brown Delaware limestone core
4,658	79.5	Est. 5			Black Delaware limestone core
WINKLER COUNTY					
28. Cranfill Bros. *et al.*, Bashara 1. Public School Land, Block 77, common corner of sections 10, 11, 22, and 23					
3,345	52.2	38.7	1.14	85	
29. Gibson & Johnson, Leck 1. Public School Land, Block 74, Section 3					
3,070	52.3	43.8	1.01	96	Gray, very porous
30. Tidal, Hill *et al.*, Amburgy 1. P. S. L., Block B-7, Section 24. Elevation, 2,995 feet. Top Blaine limestone, 3,850 feet					
3,951–55	55.4	35.1	1.33	77	Light gray and cream-colored
4,195–99	57.5	28.5	1.7	62	Dark gray; sandy
4,426–30	47.7	35.7	1.13	78	Dark gray; sandy; oil-stained
4,778–84	54.5	38.9	1.18	83	Medium gray, crystalline; 2BWPH at 4,782 feet
31. Westbrook, Hendricks 1. P. S. L., Block B-5, Section 42					
2,881	52.1	39.6	1.11	87	White
3,030–36	52.6	40.7	1.09	89	Light gray

TABLE I (*Continued*)

Interval in Feet (Depth)	*Per Cent $CaCO_3$*	*Per Cent $MgCO_3$*	*Molecular Ratio $\frac{CaCO_3}{MgCO_3}$*	*Per Cent Dolomite*	*Description and Remarks*
MISCELLANEOUS					
REAGAN COUNTY					
Skelly, Grayson-University 1-D. University Land, Block 8, Section 33, 1,980 feet from N. and 660 feet from W. lines. Elevation, 2,891 feet					
3,086–92	59.4	35.4	1.4	77	Core: oölitic; some oil
Outcrop sample. E. part of Survey No. 328, J. M. Archer, Grantee. Fossiliferous limestone from Permian on Terrell County side of Pecos River					
	91.4	5.4	14.4	12	
CROCKETT COUNTY					
Stanolind, Todd 1. G. C. & S. F., Block UV, Section 67, 1,320 feet from N. and E. lines.					
7,334	52.6	40.4	1.1	88	Ellenburger core
McMan and Amerada, Powell 1 (Powell field)					
2,495–2,500	50.6	31.6	1.35	69	Gray mottled, crystalline
2,633–40	54.3	40.8	1.12	89	Brown, "sugary" crystalline; top of pay 2,530 feet
PECOS COUNTY					
Shell, Smith 13-A					Yates field "pay"
1,712–17	51.5	42.1	1.03	92	Brown, crystalline, porous, oil-soaked

As previously stated, for ease of calculation and for purposes of comparison, all magnesium present in the limestone is assumed to be in the form of dolomite. Any calcium in excess of the amount required for a 1:1 molecular ratio with the magnesium is assumed to be in the form of pure limestone. Thus, if any sample has a $CaCO_3:MgCO_3$ ratio of 1.25:1, it would contain about 88 per cent dolomite and 12 per cent limestone.

The following points of particular interest have been brought out by these analyses.

1. Most of the limestone is highly dolomitic. The samples examined have been so widely scattered and so uniformly high in magnesium content that it appears safe to say that, with the exception of the area described under the following paragraph 3, the most of the Blaine limestone in the Permian basin probably contains at least 75 per cent dolomite and should be classified as dolomite limestone.

2. The "Brown lime" in the lower part of the Whitehorse-Cloudchief as well as the upper 100 feet of the Blaine limestone is, in general, more calcareous than the remainder of the limestone section. There is some anhydrite in the lower Whitehorse, hence the increased

calcium carbonate content might be due to the leaching action of the gypsum solution on the previously formed dolomite.

$CaSO_4$ (in solution) + $MgCO_3.CaCO_3 = 2CaCO_3 + MgSO_4$ (in solution)

3. Only four wells—the Big Lake Oil Company's University No. 179, the California Company's University No. 1, and the Simms Oil Company's Sawyer Cattle Company No. 1 in Reagan County, and Benedum and Trees' Sugg No. 1 in Irion County—penetrated limestone sections which contained very little dolomite. In the first two of the Reagan County wells and in the one Irion County well the uppermost limestone section was found to be somewhat dolomitic, but practically no magnesium was found lower than 150 feet in the Blaine limestone section. In the Simms Oil Company's Sawyer Cattle Company No. 1 the top 400 feet of the limestone section is highly dolomitic, but the lower 350–400 feet is practically pure limestone. Other wells, located near these wells, encountered the normal, highly dolomitic limestone section.

4. There appears to be no uniformity in the percentage of dolomite in the limestone at points of porosity, that is, points at which oil, gas, or water were encountered. However, in some wells there was a noticeable decrease in the amount of magnesium in the zones of apparent porosity. That such decreases are not consistent throughout the basin is shown by the following data.

A. Reagan County. The Simms Oil Company's Sawyer Cattle Company No. 1 has almost pure limestone at 3,055 feet and at 3,190 feet; at both points the well encountered a hole full of water. The "lime" above 3,000 feet and 3,115 feet is highly dolomitic; there is little or no magnesium present in the section below 3,200 feet.

B. Reagan County. Beasley's Sawyer No. 1 had a showing of oil at 2,479 feet; at 2,480 feet there is a slight decrease in magnesium content of the limestone.

C. Ector County. The Texas Company's Cosden-Connell No. 5 has a calcium carbonate-magnesium carbonate ratio of 2.38 at 4,000 feet, at which depth a hole full of water was encountered. The ratio above that point averages about 1.2.

D. Ector County. The Gulf Production Company's Connell 1-B has a jump in the ratio to 3.7 at 3,490 feet which is about the middle of the "pay." At 3,350 and 3,700 feet, which are above and below the "pay," the ratios are respectively 1.22 and 1.55.

E. Upton County. Marland's Burleson No. 3 shows a ratio of 1.55 at 2,215 feet and 2.06 at 2,260 feet. Physical appearance of these and intervening samples were the same; oil was encountered at

2,235–2,250 feet. At 2,300 feet the ratio drops to 1.21, though the well was flowing by heads at 2,298 feet. This well was drilled deep into the limestone section below the pay horizon, and between 3,900 and 4,100 feet penetrated a compact limestone in which the ratio increased to a maximum of 5.6 and which contained no oil, gas, or water.

A hole full of sulphur water was encountered at 4,500 feet; the "lime" at this point has a ratio of 1.07—almost pure dolomite. The lower part of the limestone in this well may be Clearfork in age.

These few samples show very well that there is apparently no widespread relationship between the porosity and the dolomite content. However, such a relationship might exist in certain very limited areas, which could be determined only by more detailed study.

Sufficient samples and cores are not available from wells which have penetrated deep into the limestone to furnish much information about the lower part of the section. A number of Ordovician tests have gone completely through the limestone, but most of them have been drilled with rotary equipment, the cuttings from which are of no value for analytical purposes. One cable-tool well, Marland's Burleson No. 3, in Upton County, drilled about 2,575 feet into the limestone; it has been commented on in section 4-C.

5. In one well examined, Roxana's Clark No. 1, in Tom Green County, the limestone was not Blaine, but Clearfork in age. It is particularly interesting to note that throughout the 1,700 feet of section examined the "lime" is more uniformly highly dolomitic than is the Blaine limestone.

6. The color of the so-called "Brown lime" in the Blaine appears to be due primarily to staining with oil or sulphur compounds.

7. Microscopic distinction between pure limestone and highly dolomitic limestone is very uncertain. Though not an absolute criterion, the rate of reaction in cold, 10 per cent hydrochloric acid is much more accurate.

From the standpoint of chemical possibilities there are several ways in which dolomite *might* be formed, though the conditions under which such formation will take place may be unknown or unobtainable. Some of these are here discussed.

1. *Direct precipitation from solution.*—The conditions affecting the solubility of calcium carbonate and magnesium carbonate are very similar. Three factors affect the solubility of both compounds very markedly: the amount of dissolved carbon dioxide, the amount of dissolved salt (*NaCl*), and the temperature. Of these factors the amount of dissolved carbon dioxide is undoubtedly the most important, though it, itself, is directly dependent on the other two

factors. The mode of influence of carbon dioxide is shown graphically in the following equilibrium equations.

$$CO_2 \text{ (gaseous)} \rightleftarrows CO_2 \text{ (dissolved)}$$

$$CO_2 \text{ (dissolved)} + H_2O + \underset{\text{(solid)}}{XCO_3} \rightleftarrows X(HCO_3)_2 \text{ (dissolved)}$$

Thus when the partial pressure of the carbon dioxide in the atmosphere is increased, the amount of dissolved carbon dioxide is increased; this in turn increases the amount of calcium or magnesium carbonate dissolved in the form of the respective bicarbonate. An increase in temperature of the solution will cause a decrease in the amount of dissolved carbon dioxide, thus precipitating some of the dissolved calcium and/or magnesium bicarbonate. This is further complicated by the fact that the solubility of calcium and/or magnesium carbonate *increases* as the salt content increases up to 5 per cent to 10 per cent, after which point it *decreases* as the salt content is increased.

Although these various factors tend to change the solubilities of the carbonates in the same direction, magnesium carbonate is, in general, about four to six times as soluble, molecularly, as calcium carbonate under the same conditions.

In view of the foregoing facts it is obvious that a saturated solution from which calcium and magnesium carbonates are being deposited due to a change in temperature, carbon dioxide content, or salt content will precipitate much more magnesium carbonate than calcium carbonate. Also, the complete evaporation of such a solution would tend to precipitate a "limestone" which would be predominantly magnesite. It appears, therefore, that if there is to be a primary deposition of equi-molecular quantities of calcium and magnesium carbonates from a solution saturated with both compounds, both must be added—as by the influx of a "fresh" water carrying both calcium and magnesium carbonate—in just such quantities that equi-molecular amounts must be precipitated in order to bring about equilibrium conditions with respect to the solubilities of the two carbonates. Even though we assume such ideal conditions we are assured only of the fact that the two carbonates are precipitated and have no reason to believe that they are deposited always in the form of dolomite.

2. *Change of precipitated limestone to dolomite.*—Originally deposited calcium carbonate may be converted to dolomite by a partial replacement with magnesium carbonate. Under certain conditions[5]

[5] F. W. Clarke, "Data of Geochemistry," 5th ed., *U.S. Geol. Survey Bull.* 770 (1924), p. 566.

a magnesium sulphate solution will react with calcite to form dolomite. The reaction probably takes place as follows.

$$2CaCO_3+MgSO_4 \rightarrow CaCO_3.MgCO_3+CaSO_4$$

Under different conditions this reaction is reversible,[6] that is, gypsum solutions will react with dolomite to form limestone and magnesium sulphate. This latter reaction may explain the more highly calcareous condition of the "Brown lime" in the lower Whitehorse section and of the upper part of the Blaine limestone.

There is also the possibility that when a solution saturated with magnesium bicarbonate remains in contact with precipitated calcium carbonate sludge for a considerable period of time dolomite may be formed according to the equation

$$CaCO_3+Mg(HCO_3)_2 \rightarrow CaCO_3.MgCO_3+H_2O+CO_2$$

Replacement has also been assumed to take place according to the following equation.

$$2CaCO_3+MgCO_3 \rightarrow CaCO_3.MgCO_3+CaCO_3 \text{ (in solution as bicarbonate)}$$[7]

3. Deposition as a mixture of $Mg(OH)_2$ and $CaCO_3$ (or $Ca(OH)_2$) with subsequent carbonation and conversion to dolomite. Irving[8] states:

> If the increase in alkalinity results from increase in free base alone the magnesium is rapidly precipitated as the *pH* rises above 10. Calcium precipitation likewise occurs, but more slowly. If the precipitation occurs from the addition of carbonates (changing the *pH* then by electrolysis), magnesium precipitation follows the *pH* curve, indicating its occurrence as a function of the hydroxyl ion exclusively. Calcium is precipitated chiefly by increase of carbonate ion concentration. The explanation is of course in the fact that $CaCO_3$ is relatively insoluble, $MgCO_3$ relatively soluble. $Ca(OH)_2$ on the contrary is quite soluble as compared with the insoluble $Mg(OH)_2$. There is a possibility of salt waters naturally approaching a *pH* value of 10, permitting the precipitation of both calcium and magnesium. The conditions would determine the ratio of calcium to magnesium. In waters whose alkalinity is produced by free carbonate, the calcium would far exceed magnesium in the precipitate. Were the alkalinity induced by a process removing carbonates and leaving free base, magnesium precipitation would correspondingly increase.

[6] *Ibid.*

[7] W. H. Twenhofel, *op. cit.*, p. 348.

[8] L. Irving, "The Precipitation of Calcium and Magnesium from Sea Water," *Jour. Marine Biol. Assoc. United Kingdom*, Vol. 14 (1926), p. 441; in Twenhofel, *Treatise on Sedimentation*, p. 338.

On the basis of the foregoing statement it is easy to visualize a group of conditions whereby the formation of dolomite might occur. For example, a large inland sea of high salinity and alkalinity might have fresh water, carrying $Mg(HCO_3)_2$ and $Ca(HCO_3)_2$ in solution emptying into it; the fresh waters would tend to float on top of the water of higher gravity. As the waters mix, the magnesium would normally tend to be precipitated as $Mg(OH)_2$ and the calcium as $CaCO_3$. However, conditions might exist wherein dolomite would be precipitated directly according to the equation

$$Mg(HCO_3)_2+Ca(OH)_2\rightarrow CaCO_3.MgCO_3+H_2O+CO_2$$

Even though the dolomite is not precipitated directly, later shifts might occur which would bring the fresh water in contact with the previously precipitated magnesium hydroxide—calcium carbonate sludge, when changes might take place in the following manner.

$$\underset{\text{solid}}{Mg(OH)_2}+\underset{\text{in solution}}{Ca(HCO_3)_2}=\underset{\text{solid}}{CaCO_3.MgCO_3}+2H_2O$$

$$\underset{\text{solid}}{Mg(OH)_2}+\underset{\text{in solution}}{Mg(HCO_3)_2}=\underset{\text{solid}}{2MgCO_3}+H_2O+CO_2$$

The subsequent combination of the more or less intimately mixed $CaCO_3$ and $MgCO_3$ to form dolomite can be assumed to have taken place, but the exact procedure of this change we do not know.

It is realized that we have little or no experimental results which will corroborate many of these hypotheses. However, as already stated, they are not given as explanations of how dolomite has been formed, but are merely chemical relationships which *might* take place *if* proper conditions of temperature, pressure, concentration, et cetera, were realized. Neither do the possibilities given here constitute all the conditions under which dolomite could be formed or all hypotheses proposed by other investigators of the problem of dolomite formation.

The highly dolomitic nature of the "limestone" from which much of the West Texas oil is derived may be closely connected with some of the troubles being encountered in acid-treated wells in this area. In the laboratory examination of the samples the following facts of particular interest in this connection have been noted.

1. Weak acid (less than 10 per cent HCl) had little effect on the cuttings without being heated.

2. 6 N acid (about 22 per cent) decomposed most of the cuttings readily.

3. 15 per cent acid reacted with the cuttings readily but required heating to bring about complete disintegration.

4. Oil-soaked and oil-stained cuttings were wetted by the acid with considerable difficulty. Addition of small amounts of nitric acid and heating aided very materially in increasing the rate of dissolution of such cuttings.

5. Many of the samples contained considerable material which was entirely insoluble in acid. Though some of this material was sand, much of it appeared to be a very finely divided, flocculent silt. This is probably the material which tends to choke many of the wells after acid treatment.

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GEOLOGICAL NOTES

PLACEDO OIL FIELD, VICTORIA COUNTY, TEXAS

On April 14, 1935, the Superior Oil Company of Oklahoma and F. A. Gillespie's Pickering and Henderson No. 1 was completed as a flowing well, opening a new producing area near the town of Placedo, Victoria County, Texas. Production was obtained from a sand encountered from 6,005 to 6,019 feet, approximately 1,000 feet below the top of the Frio formation. The initial production was 240 barrels of 34.6 gravity oil produced on a 5/32-inch choke with 1,700-pound tubing pressure and 2,300-pound casing pressure. The exact location of this well is 330 feet each way from the east corner of Lot 10 of the Wm. Rupley Survey, Abstract No. 480.

The fact that the Gulf Production Company owned a number of leases which would expire May 31, 1935, brought about the drilling of the discovery well at Placedo. The Gulf Company gave Donald W. Moore approximately 5,200 acres on which to drill a test. Moore made a deal with F. A. Gillespie in which Gillespie assumed the well obligation and Moore retained a small amount of the acreage. Gillespie in turn sold a ½ interest in the well and remaining acreage to the Superior Oil Company.

The test was located on what was thought to be the trend of the producing areas extending northeast from Refugio, Greta, and McFaddin. Soon after the completion of the discovery, Donald W. Moore and the Costa Oil Company commenced the drilling of a well in the north corner of Lot 14, Wm. Rupley Survey, about a mile south of the discovery well. This test encountered an oil sand from 4,757 to 4,789 feet in what is considered to be the equivalent of the Greta sand. Casing was set on this sand and the well flowed some oil, but due to mechanical difficulty with the oil screen, never made a commercial well. The gravity of oil from this sand is 24.5. Later development by other operators has resulted in several flowing wells from this horizon.

The Mor-Tex Oil Company's Mitchell No. 1, located 4,000 feet southeast of the discovery well, developed gas production in a sand from 5,273 to 5,335 feet. This made the third separate producing horizon for the Placedo field.

In October, 1934, Kenneth Dale Owen, geologist for Felmont Corporation, mapped a large subsurface "high" centering about a mile south of the town of Placedo, and recommended that his company

purchase leases on this structure. The Felmont Corporation commenced a reflection-seismograph survey of the Placedo area in February, 1935. The object of this survey was to check Owen's subsurface structure. A single traverse, consisting of 2 days of seismic work, checked the northwest dip, but it is reported that the principal land owners south of the town of Placedo would not permit geophysical work on their property. The Felmont Corporation and the Barnsdall Oil Company then purchased a lease on 3,400 acres in this area and completed the seismograph survey. The seismograph work, done by the Geophysical Service, Inc., resulted in finding a structure which closely approximated Owen's subsurface structure.

Although the Placedo field is at this time in a very early stage of development, it is possible, on the basis of subsurface and geophysical information, that it will develop into a field comparable in size with Greta.

J. D. Hedley

Houston, Texas
October, 1935

SYLVAN SHALE IN JOHN'S VALLEY

On a trip into John's Valley, September 28, 1935, H. D. Miser, John Fitts, T. A. Hendricks, and M. M. Knechtel collected some brownish black shale. The streams were exceptionally low, and the shale was exposed in the bed of a stream in an area about 15 feet wide and 20 feet long in the southwest part of Sec. 10, T. 1 S., R. 16 E., this being the southernmost exposure of shale in the valley. Upon examination, Charles E. Decker identified it as Sylvan shale, because it contains two of the diagnostic Sylvan graptolites, *Climacograptus mississippiensis* and *Diplodocus crassitestus*. Also, it has physical characteristics practically identical with those in the lower part of the Sylvan shale at the south end of Scott's Dome in the midst of the Arbuckle Mountains. The rocks of the two regions are similar in color, texture, cleavage, and fracture.

Oklahoma Geological Survey

Norman, Oklahoma
October, 1935

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates. A list of technical periodicals available for loan to members and associates was published in the *Bulletin*, Vol. 18, No. 9 (September, 1934), pp. 1215-17.

Nouvelles données sur la structure du Bassin Transylvain (New Data Regarding the Structure of the Transylvanian Basin). By D. T. CIUPAGEA. *Bull. Roumanian Geol. Soc.*, Vol. II (Bucarest, 1935), pp. 114-45; 3 pls.

After a short historical summary of the geology of the Transylvanian basin, Ciupagea defines it, according to Mrazec and Jekelius, as an internal depression in the Roumanian Carpathians which has been filled with Tertiary sediments. He distinguishes three zones from the borders to the center of the basin: (1) a border zone of Neogene sandstone, not folded and lying directly on the older basement rocks of the basin; (2) a zone of marly sandstones intensively folded in diapir folds with salt cores; and (3) a central zone of sandy marls which are less intensively folded and form the center of the basin (Pl. 1 of original article).

The basin originated, according to Mrazec, probably at the end of the Oligocene or the beginning of the Miocene and subsidence continued without interruption until the end of the Pliocene. Before the deposition of the agglomerates and eruptive tuffs of Harghita, which limit the basin on the east, subsidence must have stopped and folding commenced in the diapir zone.

STRATIGRAPHY

Around the borders of the basin, where shallow-water formations contain abundant fossils, the stratigraphic horizons are easily determined, but in the central part of the basin fossils are completely lacking and there are great thicknesses of rocks of the same lithologic character. In these areas the intercalated volcanic tuffs of wide extent and constant thickness have been used as horizon markers. Thus the "Bazna tuff," a fine dacitic tuff, associated with dolomitic limestone beds, included in a white marl series, is regarded as extending only to the upper limit of the Miocene (Sarmatian) and therefore all formations lying above this horizon are considered as Pliocene. It is also noteworthy that the overlying Pliocene formations only contain andesitic tuffs, while the Miocene tuffs are dacitic.

All lower formations, occurring between the Bazna tuff and the "Ghiris tuff" (a zone 1,500 meters thick and often called the gas formation, which includes in the middle the Sarmasel tuff), have been considered as of Sarmatian age, while formations below the Ghiris tuff are regarded as of Mediterranean age (Lower Miocene).

PLIOCENE

Pontian is exposed at Sighisoara and consists of the "Sighisoara sands" at the base, in thick beds with sandstone concretions and subordinate marls and fossiliferous conglomerates and andesitic tuffs, totalling 200 meters; in

the center are ashy marls, "Hetur marls," 200 meters thick, and at the top fine yellow sands with some sandy concretions about 150 meters thick.

Up to the present no Meotic has been recognized in the basin, but between the Sarmatian and the Pontian are a series of transition beds corresponding to the successive freshenings of the Sarmatian sea.

The entire region situated south of the Mures River, including the Plateau of Tarnava, is covered with Pontian, with outcrops, due to erosion, of the underlying Sarmatian in some domes, Bazna, Saros, Cetatea de Balta, Boian. Toward the east the Pliocene dips beneath the tuffs and andesitic agglomerates of the Calimani-Gurghiu-Harghita hills. The sands at the base contain secondary impregnations of gas.

MIOCENE

The Sarmatian or the "gas formation" of the basin consists of a 1,500-meter series of sands and marls with important intercalations of dacitic tuffs and dolomitic limestones. Its upper limit is the "Bazna tuff" and its lower limit is the Ghiris tuff, and it is divided into two parts by the Sarmasel tuff. The Sarmatian is best exposed in the southern part of the basin, north of Mures River. The section of the upper part has been determined by the outcrops in the Sincai anticline, while the section of the lower portion was determined by cores from well No. 26 at Sarmasel. This formation contains the most important primary gas horizons.

Strata of Mediterranean age are exposed along the northeast and south borders of the basin in the diapir zone and have been drilled to a depth of 300 meters in the center of the basin beneath the Ghiris tuff in well No. 26 at Sarmasel. These beds belong to the upper Mediterranean and consist of 60 meters of sands followed by clay marls with thin sandstone bands. The sands contain gas.

TECTONICS

The structure of the basin is very difficult to establish in the central portion, due to the gentle dips of the beds which had to be measured by special methods. In general, as we proceed from the border diapir zone toward the interior of the basin, the Neogene strata lie in north-south folds which become increasingly farther apart and flatter. The center of the basin is occupied by an extensive syncline (Dumbraveni syncline). Along these anticlinal folds which are broken into many minor domes, 43 domes have been mapped as favorable for commercial deposits of gas.

The writer gives the characteristics of the domes of the central basin as follows.

SOUTHWEST DOMES

1. *Copsa Mica.*—Elliptical. Main axis, west-northwest and east-southeast. Dip on flanks, 2°–4°. Area of uplift, 200 square kilometers. Maximum elevation, 275 meters. Pliocene strata at surface form cover of at least 100 meters thickness over gas-bearing Sarmatian beds. Dome explored by 5 wells; latest has found gas horizon at 600 meters in Sarmat with 100 atmospheres pressure.

2. *Bazna.*—Regular oval shape, elongate east and west. Dips, 4°–10°. Area of uplift, 90 square kilometers. Maximum elevation, 460 meters but only 160 meters elevation above syncline on north. Center of dome eroded 125

meters into the top of Sarmatian. This dome is exploited for gas and supplies the town of Medias.

3. *Cetatea de Balta-Boian.*—Regular oval form elongate north and south. Area of uplift, 200 square kilometers. Dips on north, south, and east, 2°–3°; on west flank 5°–10°. Maximum elevation, 650 meters, but only 110 meters elevation above syncline on east. Erosion in the center of the dome has extended to 220 meters in the Sarmatian. Connected on east with dome of Saros and on south with dome of Bazna. This dome has not yet been drilled.

4. *Saros.*—A great asymmetrical dome with east flank well developed for about 20 kilometers, though west flank is only 3 kilometers long. The flanks dip about 3°, but the south is steeper (5°–8°). Area of uplift, about 400 square kilometers. Maximum elevation, 650 meters. Erosion of the center of the dome has reached to 350 meters in the Sarmatian. This dome is exploited for gas for the towns of Diciosanmartin and Targu-Mures.

From the foregoing it is seen that this group of domes forms a tectonic unit of associated domal uplifts surrounded by a broad synclinal zone with base approximately at sea-level. The four domes have a total area of about 900 square kilometers and a maximum altitude of 650 meters.

SOUTHEAST DOMES

1. *The brachyanticline of Daia* lies south of Sighisoara and forms an almost horizontal north-south ridge which dips sharply under the Pliocene sands of a deep syncline at its northern end near Sard.

There is a marked discordance between the Sarmatian strata with dips of 14° and the Pliocene with dips of 3°–5°. The area of uplift is about 500 square kilometers and includes the fields of Daia, Sighisoara, and Sard. The maximum altitude is 750 meters with approximately 450 meters of the Sarmatian eroded. Exploration wells have given satisfactory results, but the structure is not yet exploited.

2. *The dome of Nades* is 8 kilometers north of Sighisoara. Regular dome. Area of uplift, 100 square kilometers. Maximum elevation, 300 meters above syncline on east, west, and north and 120 meters above syncline on south. Pliocene cover, at least 100 meters thick. Exploration wells have given satisfactory results.

3. *The dome of Bunesti-Crit* lies east of the brachyanticline of Daia and is elliptical in form with north-south elongation. The north and east flanks are well developed, while the west and especially the south flanks are poorly defined. The beds have a dip of 5°–14°. Same amount of erosion and same tectonic elevation as the brachyanticline of Daia.

4. *Brachyanticline of Cristur* lies north of Bunesti-Crit dome. Axis, north-south. Similar in elevation and amount of erosion to Daia and Bunesti-Crit.

NORTHWEST DOMES

1. *The brachyanticline of Sincai* extends northwest from Targu-Mures. Area of uplift 600 square kilometers. East flank elevation above syncline, 350 meters. West flank elevation, 470 meters. Toward the north the axis rises. West of Sincai dips of 10°–20° were noted. Farther east in Pliocene beds dips are 3°–5°. Actual measurements on elevations of beds show dips of 4°–5° near the axis and 1°–2° out in the synclines. The highest point on this brachy-

anticline is 1,300 meters above sea-level. A maximum of 900 meters of the Sarmatian (gas horizon) is eroded.

2. *The dome of Sarmasel.*—Area of uplift about 120 square kilometers. Oval shape, elongate north and south. Summit, 1,300 meters above sea-level. Dips on flanks, 2°–5°. Maximum tectonic elevation 700 meters above south syncline. About 900 meters of Sarmatian beds eroded. This dome is exploited for gas and supplies the towns of Turda and Uioara.

3. *The brachyanticline of Zau* lies south of Sarmasel and west of Sincai. Axis, northwest and southeast. Area of uplift, 200 square kilometers. Summit, 1,300 meters above sea-level. About 900 meters eroded from the Sarmatian. Dips, 10°–15° near axis and 3°–6° near syncline.

These northwest domes have a total area of about 900 square kilometers. Their altitude is about 1,000 meters above the synclines on the southeast.

CENTRAL DOMES

1. *The dome of Noul Sasesc* lies east of the dome of Copsa Mica and south of Dumbraveni. Area of uplift, 400 square kilometers. Altitude of summit, 400 meters. Dips on flanks, 2°–3°.

2. *The dome of Filitelnic* lies north of Nades and is entirely covered with Pliocene beds with dips of 1°–4°.

3. *The dome of Roaua* lies north of brachyanticline of Daia in the deepest part of the basin. Very slight dips noted.

In conclusion, the Bazna tuff is found at 1,300 meters on the summits of the domes of Sarmasel, Sincai, and Zau, and at 100 meters below sea-level in the deepest synclines, so that there is a maximum tectonic difference of level of 1,400 meters in the Transylvanian basin.

DEPOSIT OF NATURAL GAS

The natural gas of Transylvania is unlike the gas in the oil fields and contains no liquid hydrocarbons, being 99 per cent methane. This gas impregnates all permeable Neogene strata in the basin, from Upper Mediterranean (Tortonian) to the Pliocene, and is in commercial quantity in the sands and sandy marls confined between impermeable marl beds of the Sarmatian in the domes of the basin. The bordering synclines contain salt water, usually with iodine or bromine.

There are about 1,500 meters of gas-bearing beds beneath the Bazna tuff, which is regarded as the main gas formation of Sarmatian age. Actually there are some productive gas sands in the Pliocene which are exploited at Nades and Copsa Mica. Also at Sarmasel there is a deep gas horizon in the Mediterranean.

All of the strata of the Transylvanian basin, from the Mediterranean to the Pliocene, contain salt water with methane gas and H_2S. There are abundant plant remains as well as foraminifers in the beds. The regular succession of gas horizons in the domes with no signs of any faulting or dislocation make the writer believe that the gas is primary in these beds. Under hydraulic pressure the pressure of the gas in the various horizons increases 10–15 atmospheres per 100 meters.

The pressure in a gas horizon which is being exploited rationally drops slowly and regularly to a few atmospheres at the time the salt water comes

in. As an example, well No. 2 at Sarmasel dropped 11 atmospheres in 21 years, from 28 to 17 atmospheres, and well No. 8 at Bazna dropped 13 atmospheres in 9 years, from 33.5 to 20.5 atmospheres. Some of the wells have had an initial open-flow capacity of a million cubic meters daily (35 million cubic feet), but wells are not allowed to produce more than 20 per cent of open-flow capacity.

GAS RESERVES

In 1913 the gas reserves of the basin were evaluated by F. G. Clapp and A. S. Miller as 72 billion cubic meters, but with the information now at hand we realise that this is far too small.

Drilling during recent years has developed in the various fields 15 different productive gas horizons in a thickness of 1,200 meters of the formation. This is exclusive of the old exploited main gas horizons at a depth of 650–900 meters.

In order to evaluate the present gas reserves in the productive and explored domes, we shall take for comparison the main gas horizon IV on Sarmasel dome with a thickness of 50 meters. Since the beginning, in 1908, this horizon has produced 2.5 billion cubic meters with a drop in pressure from 36 atmospheres to 17 atmospheres. We consider the total quantity of gas from this horizon to be 3 billion cubic meters. A deep test on Sarmasel has encountered 5 deeper gas horizons with a total of 200 productive meters or 4 times the thickness of horizon IV. This is equal to a reserve of 12 billion cubic meters.

The gas reserves on the domes of Sarmasel, Sincai, Zau, Saros, Bazna, Copsa Mica, Nades, and Daia reach a total of several hundred billion cubic meters upon the present basis of calculation, and there is a good chance that several other domes already known may prove productive.

COMMENTS BY REVIEWER

The report of Ciupagea is a real contribution to our knowledge of the stratigraphy of the central portion of the Transylvanian Basin, and presents special interest, both from a structural and economic point of view and also because it gives the results of the geological researches of the National Methane Gas Company.

The Transylvanian basin as such did not begin to form during the formation of the Flysch overthrusts at the end of the Oligocene, because all around the borders of the basin appear nummulitic beds (Paleocene-Eogene-Oligocene) folded concordantly with the Neogene. The formation of this depression began therefore in the Danian-Paleocene and, after a short interruption, at the end of the Oligocene, when the salt deposits were probably deposited, due to concentration of sea water, the subsidence continued and sediments filled in the basin until the end of the Pliocene. From Sarmatian time, however, the depression was progressively displaced in a southeast direction. In the Quaternary only scattered lakes were present on the southern and eastern borders, beyond the new ridge of eruptives, where deposition was still continuing. From a structural point of view it is very difficult to conceive two times of folding, one for the exterior diapir zone and the other for the center of the basin, while everywhere between the two zones there is a gradual transition both in sedimentation and structure. According to our ideas the actual

tectonic pattern of the basin was developed during the latest movements due to the general elevation of the Carpathian region with compression and consolidation of the Mio-Pliocene formations. If the intensity of the folding is greater in the diapir zone than in the center of the basin, it is on account of the direct compression of the strata near the border against the rigid frame of the basin, from which the basin series are also separated by fractures.

The sole influence which the andesitic eruptions of the Calimani-Gurghiu-Harghita range had on the structure of the basin was in causing a general sinking of the eastern border of the basin along the lines of the great zones of ancient northeast-southwest fractures on the inner border of the Eastern Carpathians, due to the great weight of the eruptive masses.

The reviewer also wishes to call attention to some structural changes which affected the northern part of the basin in Quaternary times.

At the beginning of the Quaternary the Transylvanian basin was divided into two parts by an elevated ridge extending west-southwest and east-northeast in the direction of the crystalline Mesozoic spur of Turda. This same elevated zone separated the drainage basin of Somes River, which flows north and drains the northern half, from the basin of Mures River, which flows westward. This elevated ridge remains to-day in the zone of diapirs of Turda-Dej-Beclean which borders the interior basin on the north. The great erosion of the northern domes of the basin is due to this ridge.

The Transylvanian basin has also felt the influence of the gradual subsidence, since late Quaternary times, of the two great neighboring depressions, Maramures in the north within the Carpathians and the Roumanian Plain on the southeast outside the Carpathians, along the same great zone of fractures which aided the rise of the later volcanic rocks. Drawn toward the lowest of these depressions, it slopes entirely toward the southeast. Consequently the ancient ridge of Turda-Dej-Beclean disappears, but farther north there is a new anticlinal ridge which now separates the basin from the depression of Maramures-Bodrog. The anticlinal crest of the Zalau-Mezes-Lapus Mountains now forms the northern limit of the basin and Somes River has cut its channel in this down to the crystalline basement.

In regard to the special structure of the central basin, the flanks of the domes are not normal in all parts, as would appear from Ciupagea's article. Although the dips of the beds at and near the surface are low, they become increasingly steep with depth, and the beds on the flanks are drawn out thin and often slip-faulted. Recognition of this is of great practical importance, and the existence of one of these flank faults was proved by well No. 5 on the Copsa Mica dome, which disturbed the equilibrium of the gas horizon encountered between 600 and 750 meters and the gas escaped by the fault on the northeast flank, erupting 750 meters north of the well site. It was at first thought that the gas escaped along a superficial sand horizon which crops out in the valley, but later proved that escape was due to a fault.

As regards the purity of the methane gas (99 per cent) and the complete absence of liquid hydrocarbons, these are characteristic of the superficial strata with hydrocarbons, as has been noted in the southern Sub-Carpathian region at Aricesti and Boldesti in the Prahova district where deeper drilling encountered oil. We believe this also holds true for the Transylvanian basin and especially so because of the presence of traces of oil in the Mediterranean

formations along the southwest border at Ocna, Sibiului, and Turda and of ozokerite at Cricau, while the base of the Paleogene contains important oil showings along the northwest border of the basin at Jibau.

I. P. VOITESTI

CLUJ, ROUMANIA
July, 1935

Grundwasser und Quellen Kunde (Ground-Water Hydrology), 3d ed. (1935). By K. KEILHACK. Gebrüder Borntraeger, Berlin. XI and 575 pp., 1 table, 308 figs.

In general plan the edition of this standard work which has recently appeared, follows the original volume. The first major division deals with the basic sciences which are essential to ground-water hydrology and is only slightly changed. The second major division, which treats of ground-water hydrology and its related problems, has been enlarged. Many of the chapters have been expanded, and several new chapters have been added. The new chapters on geophysical apparatus and methods as applied to ground-water problems have been written by the author's colleagues—H. Reich and A. Ebert. Density, seismic, and electrical methods are discussed, but more space is devoted to resistivity methods. A brief reference is made to radioactivity methods. The third major division is a short discussion of German ground-water law and German court decisions. An innovation in this edition is the inclusion of a bibliography of 248 titles. This carefully selected list of papers should prove most useful.

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September 14, 1935

"Rochas Gondwanicas e Geologia do Petroleo do Brasil Meridional" (Gondwanian Rocks and Geology of the Petroleum of Southern Brazil). By VICTOR OPPENHEIM. 129 pp. (in Portuguese), 5 stratigraphic sections on folded insets, 53 photographs, 29 pls. (cross sections, etc.), and in separate envelope a colored geological map and a map of test wells, both on a scale of 1:2,275,000, and topographic map showing tests drilled in the Piraçicaba-São Pedro region of São Paulo, on 1:66,667. *Brasil, Ministiero da Agricultura, Serviço de Fomento da Produçao Mineral, Boletim 5* (Rio de Janeiro, 1934). Requests for copies should be addressed to the Biblioteca do Departmento Nacional da Produçao Mineral, Avenida Pasteur 404, Praia Vermelha, Rio de Janeiro, Brazil.

This book is valuable as a summary of the short field work of the author as well as that of previous investigators. It is well written, in clear Portuguese, readable by a geologist familiar with Spanish, and is well arranged and fully illustrated, being a credit to the author and to the institution that publishes it. It contains, at the front, an incomplete index, and (pp. 47–50, 127–29) two short lists of selected references.

Its study is essential to anyone who desires to know the present state of knowledge concerning the geology of Southern Brazil. Other works to be

read include those of White,[1] Woodworth,[2] Du Toit,[3] and Washburne.[4] The foundation of the stratigraphy was laid by I. C. White, with the paleobotanic assistance of David White, whose formation names and age determinations are still accepted by most authors, although Du Toit raised minor questions concerning the ages of the glaciation and of the great sheets of basalt. Woodworth gave the most detailed sections of outcropping strata, especially of the Triassic formations. Now Oppenheim presents the fullest set of well logs of these and of Permian formations. Besides adding greatly to stratigraphic knowledge, Du Toit called attention to the remarkable resemblance between the Permian-to-Cretaceous formations on both sides of the South Atlantic, indicating, he believes, a continental drift of South America away from a former union with Africa.

Oppenheim correctly uses the formation names proposed by I. C. White, for these have priority, and were accurately defined. Washburne erred in adopting the local nomenclature of the geological survey of the State of São Paulo. Both usages are correlated in Oppenheim's table ("*Quadro* II"), following p. 6. Washburne may have erred also in favoring the inferences of Du Toit as to the late Pennsylvanian age of the glaciation and the early Jurassic age of the lavas. Oppenheim improves the description of the formations by introducing new subdivisions.

Oppenheim, in disagreement with Washburne, believes the country to be highly faulted and unlikely to contain oil fields. He does not present any convincing evidence of the existence of faults in the petroliferous region, his main argument being what he considers large differences in stratigraphic elevation between some adjacent wells. In this matter one easily may be misled by a hasty examination of Oppenheim's cross sections (*Folhas* 5–17) in which he uses a vertical scale 40 times the horizontal, and in which he draws the formation patterns of each plotted log to a width of about one kilometer. To the eye of the reader this gives the appearance of sudden change in depth, suggesting faults, yet if the reader were to draw lines through identical horizons in adjacent wells, he would find that none slopes more than 5°, a common dip on the small folds of the region. In such cases the critical feature is not the

[1] I. C. White, *Final Report of the Commissão dos Estudos das Minas de Carvão de Piedra do Brasil.* Ministro da Industria, Viação e Obras Publicas Rio de Janeiro, Imprensa Nacional (1908). 617 pp. (English and Portuguese), many maps, and other illustrations.

[2] J. B. Woodworth, "Geological Expedition to Brazil and Chile, 1908–1909," *Bull. Mus. Comp. Zoöl.*, Cambridge, Massachusetts, Vol. 61, No. 1 (1912). 137 pp., 37 figs.

[3] Alex L. Du Toit, "A Geological Comparison of South America with South Africa with a Paleontological Contribution by F. R. Cowper Reed," *Carnegie Inst. Washington Pub. 381* (1927). 157 pp., 16 pls., and a colored geological map of southern Brazil, Paraguay, Uruguay, eastern Bolivia, and northern Argentina.

[4] Chester W. Washburne, "Petroleum Geology of the State of São Paulo, Brasil," *Commissão Geographica e Geologica do Estado de São Paulo, Brasil Bull. 22* (1930). 282 pp. (in English), 3 pls., 10 diagrams, 121 photographs, and 1 colored geological map by Drs. Guilherme Florence and Joviano A. Pacheco, scale 1:2,000,000. Requests for copies should be addressed to the Instituto Astronomico e Geographico do Estado de São Paulo, Departmento de Agricultura, São Paulo, Brazil. Reviewed by Helen M. Martin, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16 (1932), p. 426. *Re* geological map, see *ibid.*, Vol. 13 (1929), pp. 1215–19; and *re* late Paleozoic glaciation of southern Brazil (abstract), see C. W. Washburne, *Bull. Geol. Soc. America*, Vol. 43 (1932), p. 177.

difference in elevation of a key bed in two wells, but rather it is the direction of dip of the strata as determined in some independent way, as by observation on surface outcrops. Where this could be determined at outcrops near test wells in the State of São Paulo, Washburne found that the direction, if not the amount, of the observable surface dip corresponds with the relative elevation of strata in well logs. In a region of nearly horizontal strata, normal faulting generally rotates the displaced strata so that they dip from a fault toward the direction of upthrow. Across a fault of this type strata generally dip in a direction normal to the trend of the fault, and, characteristically, in some degree their dip is directed away from a well in which the key bed is relatively low and toward a well on the upthrow side in which the key bed is relatively high. This simple but important distinction between dip from folding and that from faulting frequently is neglected by geologists, some of whom seem prone to draw faults where the evidence indicates only bending of the strata. As in most regions, the deeper strata in the test wells of São Paulo are steeper than shallower formations, and the failure of surface dips to account fully for differences in elevation of deep key beds does not indicate faulting, because in observed cases the direction of surface dip is opposite to that of tilt from faulting. Moreover, during two years in the supposedly petroliferous area of São Paulo, Washburne could find in outcrops no sharp change of dip as in fault-drag, nor zones of rhombic jointing, nor of sheet-jointing, nor other types of local disturbance that indicate the proximity of faults, except in a few places, in all of which it was evident that the faults, if any, must have insignificant displacement.

It is true that along the southeast margin of the state, Washburne found large normal faults, with maximum vertical displacement of more than 3,000 feet, which make the high scarps along the Atlantic coast as near Santos; also a similar parallel fault along the west side of the Parahyba Valley, which provides the route for rail and automobile from Rio de Janeiro to São Paulo. These determine the main features of the topography, most important of which is the west-northwest tilt of the peneplain down which the main streams run inland away from the coastal scarp to Rio Paraná. However, in the possible oil area a few hundred kilometers west of the coastal faults, one can find no scarps of this late Tertiary and Pleistocene period of disturbance, but one does find small folds of probably middle and late Triassic age.

Even should many faults exist in the interior of the states of São Paulo and Paraná, and if the rocks were highly jointed, which they are not, experience elsewhere shows that these conditions do not prevent the retention of oil in profitable pools, nor do they necessarily cause any seepage of oil. Thus, in most of the highly faulted fields of the Rocky Mountains, oil seepages are lacking, even in places where productive sands lie within 1,500 feet of the ground surface; and in the Salt Creek field, Wyoming, numerous faults have not permitted recent communication between a great area of salt water in the First Wall Creek sand, and oil in the Second Wall Creek sand only a few hundred feet below it. Not merely do faults fail to destroy many oil fields, but commonly they fail even to create any surficial seepage. Oppenheim's statement that the lines of *chapapoteras* in Mexico occur along faults is open to question, for wells fail to reveal corresponding displacement in the shallow strata. Early excavations for the Eagle Oil Company showed that some of these lines of seepage lie along mere joints, which in part are followed by dikes.

As elsewhere, the larger known faults appear to have been sealed against fluid migration. Oppenheim may well have omitted his reference to supposed faulting as inimical to the occurrence of oil fields in Southern Brazil.

Oppenheim agrees with previous authors that the heavy black oil and asphalt found above the Upper Permian black shale (Iratí formation) were derived from the latter. He observes that the Iratí shale was overlain by only 300–400 meters of younger strata, an amount insufficient in his opinion to cause the generation of oil. To this he should have added a similar or greater thickness of basalt, near the outcrops of the formations, and probably several times this amount of basalt under central parts of the Paraná basin. Even so, the cover above the Iratí black shale was rather thin, say 2,500 to possibly 5,000 feet. Like others, he is tempted to call on the heat of the locally numerous igneous intrusions. Unfortunately we do not yet know what depth of burial is necessary to generate petroleum. Perhaps we should consider also the fact that in the few occurrences that seem genetically tied to the heat of igneous intrusions, namely, those of Taranaki, New Zealand, of southern Alaska, and of eastern Oregon, the heavy asphaltic oils or residues contain an appreciable percentage of phenols, substances characteristic of coal tars, but which definitely are absent in all other crude oils in which phenols have been sought. Available analyses do not state whether phenols have been sought in the heavy oils and residues of Southern Brazil. Regardless of the cause of its formation, there is no doubt that the now hardened asphaltic residue of São Paulo, some of which at outcrops barely flows on a hot day, once must have had the liquidity required to enable it to flow through sandstone horizontally for at least one kilometer, the maximum exposed length of an asphaltic sand at Porto Martins,[5] saturating the sandstone to a maximum thickness of 60 feet.

In few words Oppenheim dismisses the suggestion of Washburne that the small traces of lighter oil found in the Itararé (glacial) beds, of doubtful Permian age, seem to represent a type distinct from the black oil in the higher Permian and Triassic strata, and that the oil of the former type, possibly paraffinic, may have risen from Devonian or other concealed strata. Oppenheim (p. 113) seems to doubt the accuracy of Washburne's description of one of these oils from a well at São Pedro, as "light greenish yellow," possibly because Washburne failed to write that Dr. Eugene Doutra, then in charge of Governmental drilling, showed him a sample of this color. If a laboratory report on this oil called its color "red" or "chestnut," one may suspect that the sample was held not against a black opaque object, but was held so that light could pass through it. Of similar significance in regard to the possibility of deeper oil, is Oppenheim's doubt (p. 113) concerning the validity of the green highly fluid oil in well No. 1 of the Cia Cruzeiro do Sul, at Bofete, São Paulo. Presumably he failed to appreciate the description by Washburne (p. 220) of the intimate penetration of this oil throughout a sample of saturated typical tillite, a degree of penetration that hardly could be imitated artificially, indicating beyond reasonable doubt that the green oil occurs in the glacial beds. Oppenheim's remark that I. C. White reports no oil in earlier wells in the same vicinity has no bearing on this matter, because the older wells were much shallower. Oppenheim is right in saying, indirectly, that Washburne presents only meager evidence of the occurrence of a distinct type

[5] Chester W. Washburne, *op. cit.*, pp. 145–47, Figs. 112, 113.

of oil in the lower horizons (Itararé formation), and Washburne admits that his suggestion was hardly more than "grasping at a straw" in the hope of finding better oil at greater depth in the undrilled central parts of the Paraná basin. Yet even meager evidence seems more valuable than unsupported opinion to the contrary. That deeper source beds, the dark marine shales of the Devonian, and possibly marine Carboniferous strata, may exist under parts of the Paraná basin, seems quite possible, not only because of the presence of Devonian shales in Paraná and of marine Carboniferous in southern Paraguay and Uruguay, but also because of the general frequency with which stratigraphic *lacunae* at the margins of other great basins are filled at least partly by other intervening strata in central parts of the basins.

The distribution of the basal Devonian sandstone along the upper part of a broad west-plunging anticlinal arch in Paraná, with overlying soft Devonian shale limited to the crest of the arch, seems unnatural to one familiar with the stratigraphic effects of erosion only by water. Such erosion commonly removes the higher strata from the crests of upwarps and lets them remain only in synclines. The opposite type of distribution of strata, as shown by the position of the Devonian rocks of Paraná and of southern São Paulo, seemed inexplicable to Washburne until he observed (pp. 240–41) that it is just what one should expect from erosion below an ice sheet that was concentrated in two lobes on both sides of higher ground, over which the ice was thin or temporarily absent. One of these ice lobes seems to have moved westward along the north side of the Paraná arch, where tillite is in contact first with the basal Devonian sandstone, and then farther north with the underlying metamorphic rocks. South of the arch the other ice lobe likewise cut through all the Devonian strata and into the Basement complex. On top of the arch the ice not only failed to remove the Devonian ("Ponto Grosso") shale above the basal sandstone, but failed also to remove a few hundred feet of soft clays and sands of presumably early glacial (Permian?) age which, in the city of Ponto Grosso, unconformably overlie Devonian shale, and unconformably underlie glacial tillite. The surface of the soft sediments in that city shows no trace of the crumpling from glacial thrust which Washburne found to characterize areas in which the late Paleozoic glaciers eroded soft beds. The west-plunging arch of Paraná is an area of glacial deposition, while the synclines north and south of it are areas of glacial erosion that cut through the Devonian strata and into the Basement complex. This could result only from westward or northwestward movement of the ice, and would be quite impossible from northward movement, which Oppenheim infers, without giving any specific evidence. The argument of Washburne (pp. 31–2, Figs. 26, 27, and sketch No. 1) that small overthrusts and overturned folds seen in banded clays (varve shales?) north of Porto Feliz, São Paulo, were due to the thrust of ice moving westward or northwestward, is questioned by Oppenheim (p. 13), because Oppenheim found similar structures in post-glacial formations, structures which he thinks were produced by igneous intrusions. Washburne admits that his observations were made in shales locally "baked" by igneous intrusion, probably from a thin Triassic sill of basalt beneath them. Yet he never has seen similar structures near small igneous intrusions, and is rather inclined to doubt that these particular structures could have been produced by anything other than westward or northwestward thrust by an overriding glacier. This observation on small outcrops perhaps is less significant than the

preceding observation that Devonian shale crops out only at the top of the wide west-plunging Paraná arch, which gives more reliable proof that the late Paleozoic glaciers moved westward or northwestward along the arch, not northward across the arch.

So far as known, this is the first case in which the nature of glacial erosion seems to determine the probable distribution of possible source beds of oil. Inasmuch as Washburne's observations indicate that the areas of exposed glacial deposits lie near the western margin of the ice, one may infer that the hypothetical Devonian and Carboniferous marine source beds may not have been stripped away from western parts of the Paraná basin. Matters of this nature, in which Washburne was much interested, are not considered by Oppenheim.

In conclusion, it seems reasonable to infer that neither Oppenheim nor Washburne has reached the truth. The State of São Paulo has approximately the area of Texas, but Washburne could spend only 3 years in it, not more than 2 of which could have been devoted to actual field work. Oppenheim spent only 6 months within an area about three times as great. Washburne had most capable associates, especially Drs. Joviano Pacheco, Guilherme Florence, and Domicio Pacheco e Silva, the first two of whom had spent most of their adult lives in studying the geology of the region. In his report Oppenheim mentions no assistants. This seems to give Washburne some advantage, but none of his associates is to be considered responsible for any of his published conclusions, regardless of the extent to which he drew upon their knowledge. In spite of this, Washburne admits that, within the time involved, no man is capable of judging the ultimate merits of an area so great. He is glad to see the practically complete disagreement of opinion expressed by Oppenheim, because new ideas and new observations help to find the truth.

CHESTER W. WASHBURNE

149 BROADWAY, NEW YORK
September 21, 1935

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* "Premières recherches sur les hydrocarbons minéraux dans les états du Levant sous mandat Français" (Preliminary Research for Mineral Hydrocarbons in the French Mandated States of the Levant). By L. DUBERTRET. *Annales de l'Office National des Combustibles Liquides* (Paris), Vol. 9, No. 5 (1934), pp. 877–99, and Vol. 10, No. 1 (1935), pp. 31–54; 5 pls., 10 figs.

In 1931 the French High Commissioner requested L. Dubertret, head of the geological department, to make a detailed examination of the petroleum resources of the French Mandated States of the Levant, namely, Syria and Lebanon.

The article under review summarizes the principal results obtained, both from the point of view of the type of petroleum occurrence and from that of the general geology.

The first part deals with the orographic and geologic features of the area. The author distinguishes two zone : the mountainous, coastal zone, a region of horsts and grabens, the stratigraphic series of which extends, under a prevailing limestone facies, from the Jurassic to the Eocene, with some outcrops of Oligocene, Miocene, and Pliocene; and the inland desert zone with

simple plateau structure for the most part. In the latter zone the Paleozoic basement crops out at one point and is everywhere else covered by a series of Cretaceous, Eocene, Oligocene, and Miocene formations of varied facies.

A description of the petroleum occurrences occupies the second and most detailed part of this study.

In it the author reviews in turn the different regions which are known to contain occurrences, or indications, of hydrocarbons. First, the occurrences of bitumen or asphaltic limestone, some of which have been exploited, are briefly described. Then the question of oil occurrences is discussed.

1. *Asphalt occurrences in Jericho district.*—The occurrences in Jericho, in Palestine, are briefly described. Here the bitumen impregnates three horizons of the Senonian, the amounts varying from approximately 10 to 22 per cent.

2. *Asphalt occurrences at Makaren, Valley of Yarmouk.*—Calcareous shales and limestone beds are impregnated with bitumen and belong to the Maestrichtian. Attempts have been made to extract oil by partial combustion or distillation, but the amounts obtained (1–6 per cent) are too small for commercial exploitation.

3. *Bitumen occurrences at Hasbaya.*—The region of the sources of the Jordan has long been known for its pure bitumen, which has been exploited. It fills cracks or faults in the Senonian chalk. The author considers that it originates in that chalk.

4. *Asphalt and petroleum occurrences at Lattaquié.*—Numerous small occurrences are scattered in the valley of the Nahr-el-Kebir. The Cenomanian, the Senonian, and the Eocene are in various places impregnated with bitumen. Here again the author considers that the bitumen originates in the Senonian and is of secondary origin in the Cenomanian and Eocene. These occurrences are being exploited.

5. *Petroleum occurrences at Tchenguène (Alexandret a).*—A small petroleum seepage has long been known on the coast, south of Alexandretta. It appears on an anticlinal dome which affects a small Miocene basin between the sea and the mountain range of Kizil Dagh. In addition to this seepage, a gas spring in the middle of the *roches vertes* is known to exist.

6. *Bituminous sandstone at Djebel Bicheri.*—The Djebel Bicheri is the northeast extremity of the Palmyra ridge, and shows a series from the Cenomanian to the Miocene. The structure is an extensive, plunging anticline broken by secondary domes. Here there are bituminous sandstones, said by the author to be Burdigalian, but which the reviewer considers more likely to be Oligocene.

7. *Djebel Abd el Aziz.*—Deeply eroded as far as the primary formations, this structure has only a purely geologic interest and displays a fine series, from the Aptian to the Miocene.

8. *Djebel Sindjar.*—A colored geologic map illustrates the geology of this region, which shows a large anticline eroded to the Senonian. In the Eocene, bituminous limestones are known to exist. Some small domes, which continue the Djebel Sindjar toward the west, are considered by the author to be of interest.

9. *Karatchok Dagh.*—This region shows an anticline in the Pliocene conglomerates and sandstones, covered by basalt.

In conclusion the author draws attention to the possible interest for oil prospection of certain closed structures, the discovery and study of which will be the aim of the companies which have acquired research permits.

It is to be regretted that the author, in his conclusions, has not brought out some analogies and differences between the geology of Eastern Syria and Iraq.

This interesting study, based for the most part on the personal work of the author, makes an important contribution to the geology of Syria and can be usefully consulted in conjunction with the geologic map (scale 1:1,000,000) of Syria and Lebanon, by the same author (*Rev. Geogr. Phys. et Geol. Dyn.*, T. VI, Fasc. 4, Paris, 1933).

H. DE CIZANCOURT

PARIS, FRANCE
September 24, 1935

RECENT PUBLICATIONS

ABYSSINIA

The following references are taken from *"Bibliography and Index of Geology Exclusive of North America," Vol. I, 1933 (1934) and Vol. II, 1934 (1935), by John M. Nickles and Robert B. Miller, *Geol. Soc. America* (New York).

"La mission scientific de l'Omo," by C. Arambourg and R. Jeannel. *Comptes Rendus Acad. Sci. Paris*, Vol. 196, No. 25 (June 19, 1933), pp. 1902–04. Short account of expedition to southern Abyssinia to obtain vertebrate fossils.

"Observations sur la bordure nord du lac Rodolphe," *ibid.*, Vol. 197, No. 16 (October 16, 1933), pp. 856–58; sketch map. Shore-line changes, north end of Lake Rudolf, Kenya Colony.

"Le formations prétertiaires de la bordure occidentale du lac Rodolphe (Afrique Orientale)," *ibid.*, Vol. 197, No. 25 (December 18, 1933), pp. 1663–65. Stratigraphy of pre-Tertiary formations of western border of Lake Rudolf, Kenya Colony.

"Un nouveau genre d'Équidé quaternaire de l'Omo (Abyssinie), *Libyhipparion ethiopicum*," by L. Joleaud. *Bull. Geol. Soc. France*, Ser. 5, Vol. 3, Nos. 1–2 (1933), pp. 7–28; 1 pl. New genus and species from Pleistocene deposits of Omo Valley.

"Saggio di una carta geologica dell'Eritrea, della Somalia e dell'Etiopia alla scala di 1:2,000,000," by Giuseppe Stefanini. *Consiglio Naz. Ricerche, Com. Geol.* (Fierenze, Italy, 1933). 179 pp., 18 figs., 6 pls., 2 colored geol. maps. Explanatory text, with geological maps, of geology of Eritrea, Abyssinia, and Somaliland.

"Les formations éruptives du Turkana (Afrique Orientale)," by Camille Arambourg. *Comptes Rendus Acad. Sci. Paris*, Vol. 198, No. 7 (February 12, 1934), pp. 671–73. Age relations and structure of eruptive rocks (Miocene) of Turkana, Kenya Colony.

"Mammifères miocènes du Turkana (Afrique Orientale)," *idem. Ann. Paléont.* (Paris), Vol. 22, Nos. 3–4 (March, 1934). 26 pp., 5 figs. incl. sketch map (1:2,000,000), 2 pls. Miocene mammals.

"Les résultats géologiques de la Mission de l'Omo (1932–1933)," *idem. Comptes Rendus Séances Soc. Géol. France* (Paris), No. 5 (March 5, 1934), pp. 63–64. Stratigraphic and paleontologic results of expedition to study Tertiary deposits bearing vertebrate fossils of Omo Valley, Abyssinia.

"Découverte d'un gisement de mammifères burdigaliens dans le bassin du Lac Rodolphe (Afrique Orientale)," *ibid.*, No. 14 (November 20, 1933), pp. 221–22. Discovery of mammal-bearing Burdigalian deposit (Miocene) in Lake Rudolf basin, Kenya Colony.

"Études pétrographiques en Ethiopie," by E. W. Molly. *Comptes Rendus Soc. Phys. et Hist. Nat. Genève*, Vol. 51, No. 2 (April–July, 1934), pp. 49–53, 72–79. Three notes on basalts and alkaline rocks of Abyssinia.

"Le Ouallaga géologique et minier (Ethiopie)," *idem. La Chronique des Mines Coloniales* (Bur. d'Études Géol. et Min. Coloniales, Paris), Vol. 3, No. 29 (August 1, 1934), pp. 252–61; 1 fig. (sketch map, 1:1,000,000). Geology and mineral resources (gold, platinum, etc.), of Ouallaga region, western Abyssinia.

"Molluschi del giuralias della Somalia; introduzione-cefalopodi," by G. Stefanini. *Palaeontographia Italica* (Siena, Italy), Vol. 32, Supplement 1 (1933), pp. 1–53. Jurassic Cephalopoda from Somaliland Peninsula, especially Italian Somaliland and Abyssinia.

"Notizie sulle formazionii plioceniche e pleistoceniche della Somalia," *ibid.*, pp. 55–56; 8 figs. incl. sketch maps. Stratigraphy and deposition of Pliocene and Pleistocene of Italian Somaliland.

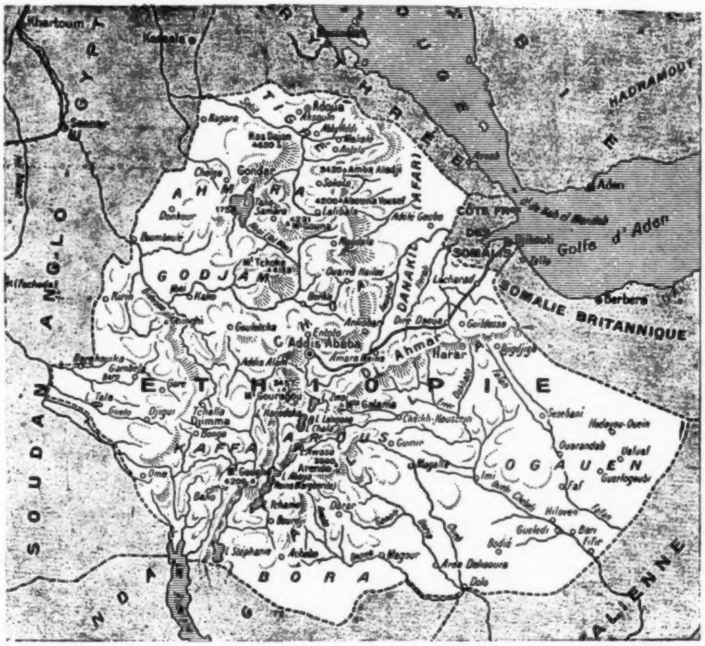

FIG. 1.—Map of Abyssinia. By courtesy of *La Revue Pétrolifère*, No. 647 (September 7, 1935), p. 1139.

ALBERTA

* "Alberta Oil and Gas Industry," by W. Calder. *Jour. Inst. Petrol. Tech.* (London), Vol. 21, No. 143 (September, 1935), pp. 753–73; 9 figs.

ALGERIA

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ECUADOR

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GENERAL

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* "El laboreo minero en los yacimientos petrolíferos" (Mining for Petroleum by Shafts and Galleries), by H. Platz. *Bol. Informaciones Petroleras* (Buenos Aires, Argentina), Vol. 12, No. 130 (June, 1935), pp. 13–24; No. 131 (July, 1935), pp. 43–68; 6 figs.

"Bench Marks in the United States." *U. S. Coast and Geodetic Survey Spec. Pub. 131* (1935). Reprint of part of original Appendix 3, Report for 1903 (now exhausted), containing descriptions not printed in other Survey publications. Supt. Public Documents, Govt. Printing Office, Washington, D. C. Price, $0.25.

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INDO-CHINA

* "Stratigraphie et structure de la presqu'île indochinoise" (Stratigraphy and Structure of the Indo-Chinese Peninsula), *anon. La Chronique des Mines Coloniales* (Bur. d'Études Geol. et Min. Coloniales, Paris), Vol. 4, No. 42 (September 1, 1935), pp. 289–92; map of Indo-China; stratigraphic table. Abstracted from: J. Fromaget, "Observations et réflexions sur la géologie stratigraphique et structurale de l'Indochine," *Bull. Geol. Soc. France* (Paris), 5th Ser., Vol. 4 (1934), pp. 101–64; *idem*, "Sur l'existence du Trias inferieur à facies océanique au Sud de Luang Prabang (Laos) et sur la paléogéographie de l'Asie Sud orientale à cette époque." *Comptes Rendus Acad. Sci.* (Paris), Vol. 201, No. 4 (July, 1935), pp. 284–86.

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OKLAHOMA

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PERU

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RUSSIA

* "On the Stratigraphy of the Artinskian Stage of the Orenburg Region in the Urals," by E. V. Voinova. *Problems of Soviet Geology* (Moscow), No. 7 (1935), pp. 657–70, including a lithologic and faunal table in English. English summary, pp. 670–71.

SOUTH AMERICA

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TEXAS

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"The Midway Group of Texas," by Julia Gardner, T. W. Vaughan, and W. P. Popenoe. *Ibid., Bull. 3301* (1935). Includes description of macrofossils, illustrated by 28 heliotype plates. Price: paper, $2.00; cloth, $2.75.

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BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
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Memorial

CLYDE M. BENNETT

Clyde M. Bennett was born in Walkersville, West Virginia, on October 15, 1881, and died on April 25, 1935, in Dallas, Texas. He is survived by his widow, Martha R. Bennett, his parents, Mr. and Mrs. Hanson Bennett, and four children, Carol M. Bennett, Kenneth P. Bennett, Donald M. Bennett, and Martha L. Bennett.

Mr. Bennett attended the University of West Virginia, doing geological work in the field with the topographic branch of the United States Geological Survey during the summer seasons. He graduated in 1909 with a degree of Bachelor of Science in Civil Engineering. At college he was elected a member of the Sigma Phi Epsilon fraternity and remained an active alumnus.

In February, 1910, he was married to Miss Martha R. Martin of Morgantown, West Virginia, who bore him five children, one of whom, Clyde M. Bennett, Jr., died in infancy in 1919. Regardless of the success which came to him with all its attendant responsibilities, Mr. Bennett's first devotion was always to his family. Their companionship, happiness, and enthusiasm have always been an inspiration to those who knew them.

His early training fitted him for the technical life which he later followed. In 1909, after graduating from the University, he entered the employ of the Philadelphia Company at Pittsburgh, Pennsylvania, in the land and geological department, and continued with this company until 1913, when he was employed by Benedum-Trees of Pittsburgh, Pennsylvania, to do oil and gas prospecting in Arkansas and Oklahoma. He left Benedum-Trees in 1915 to take a position with the Arkansas Natural Gas Company at Shreveport, Louisiana, and remained with this organization doing engineering and land work until December, 1919, at which time he joined the Louisiana Oil Refining Corporation at Shreveport, Louisiana, as assistant to the president in charge of land and production activities. He assisted in the organization of all the operating departments of this company, and, in 1921, became vice-president and director in charge of operations until transferred to New York in 1926. In the fall of 1926 he became president of the Trinidad Oil Fields Operating Company, and shortly thereafter managing director of that company's subsidiary in the Island of Trinidad, British West Indies, engaged in drilling, producing, and marketing crude oil.

In September, 1928, Mr. Bennett joined the Vacuum Oil Company as general manager of the crude oil department, with headquarters at Houston, Texas. When the Socony-Vacuum Oil Company, Incorporated, was organized in 1931, by a merger of the Standard Oil Company of New York and the Vacuum Oil Company, he became a vice-president of the Magnolia Petroleum Company, an operating subsidiary, at Dallas, Texas, and was the head of the geological, land, and engineering departments of this company at the time of his death.

Mr. Bennett was a member of the American Institute of Mining and Metallurgical Engineers and of the American Association of Petroleum

Clyde M. Bennett

Geologists. He was also a member of the American Petroleum Institute from its organization and a councillor of that organization since 1924. While located at Shreveport, Louisiana, he assisted in the organization of the Arkansas-Louisiana Division of the Mid-Continent Oil and Gas Association, and was its first president.

Mr. Bennett was an active member of the Presbyterian Church and served as one of its deacons for many years. Fraternally, he was a member of both York Rite and Scottish Rite Masonic Bodies, including the Shrine.

In 1930, in recognition of Mr. Bennett's ability as a scholar and an oil man, he was invited to lecture on "The Oil Industry" at Princeton University under the Cyrus Fogg Brackett Foundation, and was given an honorary membership in the Princeton Engineering Association.

One of Mr. Bennett's last activities was his management of the 1934 convention of the American Association of Petroleum Geologists held at Dallas, Texas. The smoothness with which this convention was accomplished best illustrates the outstanding characteristics by which geologists will remember him. This genius for creating harmony was the result of an unlimited capacity for friendship added to a superb power of self-control. His sense of humor was adequate to any situation, and he had the faculty of instinctively believing the best of everyone. This inspired those who worked under him, and made him a natural leader. So powerful was the balance and sanity of his character that the influence of Clyde Bennett will live on in the lives of those with whom he dealt.

SHERIDAN A. THOMPSON

DALLAS, TEXAS
September 23, 1935

JAMES DONALDSON SISLER

James Donaldson Sisler died on Sunday, June 16, 1935, en route in an ambulance from Myersdale, Pennsylvania, to a Pittsburgh hospital, from injuries received in an accident the night before when thrown from a "whip ride" at a carnival.

His untimely death was a severe shock to his many friends, acquaintances, and associates throughout the Appalachian area.

Mr. Sisler was born on September 2, 1896, at Morgantown, West Virginia, the son of Millard T. and Nanna Donaldson Sisler.

After completing the grade and high schools at Morgantown, he attended West Virginia University, where he was graduated with an A.B. degree, majoring in geology, in 1919. From 1919 to 1921 he attended Johns Hopkins University, where he received B.S. and M.A. degrees in geology.

During his comparatively short professional career his experience was varied, he having held several important positions. His major interest was in non-metallic geology, especially of coal, oil and gas, and to a lesser degree clay, limestone, and building products. Publications by Mr. Sisler on these subjects appeared in scientific and technical journals and State publications.

At the time of his death, Mr. Sisler was employed as a geologist by the United States Steel Corporation. Prior to this appointment, he had held the following positions.

Assistant geologist, Maryland Geological Survey
Consulting geologist, Maryland State Highway Commission
Associate State geologist, Pennsylvania Topographic and Geologic Survey
Consulting engineer, Pennsylvania Public Service Commission
Consulting geologist, Securities Bureau of Pennsylvania
Consulting engineer, Pennsylvania Giant Power Board
Consulting geologist, Water Power and Resources Board of Pennsylvania
Consulting mining engineer, Pennsylvania Department of Mines
Member, United States Coal Commission
Consulting geologist, United States Geological Survey
Consulting mining engineer, United States Bureau of Mines
Advisory member, School of Mineral Industries, State College of Pennsylvania
Advisory member, School of Mining and Ceramics, Ohio State University
State geologist of West Virginia
Consulting geologist, West Virginia Public Service Commission

Mr. Sisler was very active in numerous geological and engineering societies. Memberships were held in the following organizations

Fellow, Geological Society of America
Society of Economic Geologists
Association of American State Geologists
American Gas Association
American Petroleum Institute
American Association for the Advancement of Science
American Association of Petroleum Geologists
American Institute of Mining and Metallurgical Engineers
Coal Mining Institute of America

He is survived by his wife, daughter, and father.

PAUL H. PRICE

MORGANTOWN, WEST VIRGINIA
July 11, 1935

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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

The Panhandle Geological Society, John E. Galley, secretary, Shell Petroleum Building, Amarillo, Texas, held a field trip to Las Vegas, New Mexico, September 14. Geologic sections ranging from pre-Cambrian to Cretaceous were examined.

Glenn D. Hawkins has moved from Duncan, Oklahoma, to 423 South Allegheny, Tulsa, Oklahoma.

H. V. Tygrett may be addressed in care of the Atlantic Oil Producing Company, Magnolia Building, Dallas, Texas.

P. W. Goodman, formerly with the Smith and Story Drilling Company, Alice, Texas, is now with the Harrell-Davis Oil Company, Ramsey Tower, Oklahoma City, Oklahoma.

Hollis D. Hedberg has changed his address from 1165 Lincoln Avenue, Palo Alto, California, to the Venezuela Gulf Oil Company, Apartado 234, Maracaibo, Venezuela, S. A.

J. Brooks Knight, formerly in the geology department of Occidental College, Los Angeles, California, is now in the geology department of Princeton University, Princeton, New Jersey.

Earle R. Wall has changed his address from Victoria, Texas, to 644 Patterson Avenue, San Antonio, Texas.

Lyman C. Reed, who has been with the Lago Petroleum Corporation, at Maracaibo, Venezuela, may now be addressed at Cia Romano Americana, 126 Calea Victoriei, Bucharest, Roumania.

Theodore Chapin has changed his address from Johnson Hall, University of Washington, Seattle, to Cities Service Petroleum Company, Ltd., 1166 Subway Terminal Building, Los Angeles, California.

L. K. Mower, formerly with the United British Oilfields of Trinidad, Ltd., 15 Abercromby Street, Port of Spain, Trinidad, B. W. I., is now with the Caribbean Petroleum Company, Apartado 19, Maracaibo, Venezuela, S. A.

J. M. Vetter, consulting geologist and formerly with the Rio Bravo Oil Company, Houston, has been appointed head of the geological department for the Pan American Producing Company, Houston, Texas.

R. A. Liddle, chief geologist for the Pure Oil Company in the Texas producing division, with headquarters at Fort Worth, resigned effective September 1. F. E. Poulsen has been promoted to fill this vacancy.

Alfred Bentz, director of the geological planning and execution of the State drilling program in Germany, and head of the Institute for Oil Geology founded by the Prussian Geological Survey in 1934, has accepted the chair of geology at the Technical University in Hannover.

R. T. SHORT, geologist for the French Oil Corporation, Laredo, has moved to Corpus Christi, Texas, and opened general offices for that concern, in the Nixon Building.

WILLIAM A. WATKINS, formerly with the Standard Oil Company, Plaza Huincul, F. C. Sud. Argentina, is now with the Carter Oil Company, Tulsa, Oklahoma.

HENRY ROGATZ, consulting geologist of Amarillo, Texas, and H. T. PATTERSON, have opened a consulting office at 301 Rule Building.

GRAHAM B. MOODY, of the Standard Oil Company of California, has moved from Los Angeles to San Francisco. His office address is 225 Bush Street.

WILLIAM PIERCE, DAVID ANDREWS, FRED HAASE, and FRED WALDRON composed a party of the United States Geological Survey working near Cody, Wyoming, during the past field season.

T. F. HARRISS, recently teaching geology at Pomona College, Claremont, California, has gone to Arabia for the Standard Oil Company of California.

R. C. LANE is taking graduate work at the University of Kentucky, at Lexington.

ROBERT BALK, recently of Hunter College of the City of New York, may now be addressed at the Department of Geology, Mount Holyoke College, South Hadley, Massachusetts.

DONALD W. ST. CLAIR, who completed special courses in geology at Colgate University, Hamilton, New York, this year, is with the geological staff of the Shell Petroleum Corporation, Tulsa, Oklahoma.

CHARLES S. AGEY, after completing graduate work at the University of Rochester at Rochester, New York, is in the geological department of the Amerada Petroleum Corporation, Tulsa, Oklahoma.

LAWRENCE LEES, of Iowa City, Iowa, and recently with the United States Geological Survey, has a position with the Mid-Continent Petroleum Corporation, Tulsa, Oklahoma.

GERALD F. LOUGHLIN, of the United States Geological Survey, Washington, D. C., has been selected chief geologist of the Survey, succeeding Timothy W. Stanton, October 1. LOUGHLIN entered the Survey in 1912 and has served as geologist in charge of the Division of Mineral Resources and of the Section of Metalliferous Deposits. STANTON entered the Survey in 1889 and for 30 years was in charge of the Section of Paleontology and Stratigraphy.

FREDERICK G. CLAPP, consulting geologist, 50 Church Street, New York, was engaged in geological studies in Haiti and the Dominican Republic for 3 months in the spring and early summer.

FRANZ BEYSCHLAG, president of the Prussian Geological Survey, died on July 23, 1935, at the age of 79 years.

WILLIAM J. FOWLER is with The Texas Company at Wichita Falls, Texas.

GRAHAM W. RENFRO, JR., of Tulsa, has been doing soil erosion work at Stillwater and Clinton, Oklahoma.

CHESTER W. WASHBURNE, 41 Emerson Avenue, New York, is engaged in a study of migration of oil and its gravities in the Gulf Coast and Rocky Mountain regions.

On September 16, the San Antonio Geological Society conducted a symposium on shallow oil fields producing in the Navarro-Taylor section of Upper Cretaceous age in the San Antonio area, and in connection with this program presented the following papers: "Geology of the Pearsall Field," by JOHN THOMPSON of the Amerada Petroleum Corporation; "The Somerset Field," by JOE DAWSON; "The Ina Field," by Edward D. Pressler of the Humble Oil and Refining Company; and "Notes on Reserves in the Dobrowolski Pool," by I. R. SHELDON.

The Shreveport Geological Society held its 12th annual field trip on October 4, 5, and 6. H. D. MISER, of the United States Geological Survey, led the party to points of interest in the Ouachita Mountains of Oklahoma.

The following appointments have been made in the University of Texas faculty at Austin: R. T. HILL to be honorary lecturer in petroleum engineering (he was the first professor of geology at the university); R. H. CUYLER advanced to adjunct professor of geology; and E. C. SARGENT to be instructor in the department of petroleum engineering, succeeding R. B. NEWCOMBE, JR., resigned.

E. H. SELLARDS, director of the University of Texas Bureau of Economic Geology at Austin, announces in his *News Letter* of September the publication of *Bulletin 3301*, JULIA GARDNER's monograph on "The Midway Group of Texas," prepared in coöperation with the United States Geological Survey. Another bulletin, now in page proof, is Volume II of "The Geology of Texas, Structural and Economic Geology," exclusive of petroleum, but including a structural map of the state,

The regents of the University of Texas are planning the erection of a State Museum on the university grounds, according to E. H. SELLARDS, secretary of the Museum Association. In connection with the Texas Centennial Celebration in 1936, the Texas Legislature has provided $225,000 and the Federal Government has provided $300,000 for museum purposes.

At a meeting of the Tulsa Geological Society, Monday evening, October 7, H. A. IRELAND presented a paper on "The Use of Insoluble Residues for Correlation in Oklahoma."

The Midland Geological Society has elected the following officers to serve for the coming year: president, JAMES FITZGERALD, JR., Skelly Oil Company; vice-president, W. D. ANDERSON, Amerada Petroleum Corporation; secretary-treasurer, JOSEPH H. MARKLEY, JR., The Texas Company, Midland, Texas.

CARL J. NEER, geologist with the Humble Oil and Refining Company, has been transferred from Houston to Corpus Christi, Texas.

EDWARD T. MERRY and V. C. PERINI, JR., have transferred their headquarters from San Angelo to Abilene, Texas.

The Houston Geological Society has elected the following officers for the ensuing year: president, M. C. ISRAELSKY, United Gas Company; vice-president, PHIL F. MARTYN, Houston Oil Company; secretary-treasurer, O. L. BRACE, consulting geologist, Houston, Texas.

JOHN H. THACHER, JR., Standard Oil Company, has been transferred from the petroleum engineering division at Taft, to the land and lease division, San Francisco, California.

J. BEN CARSEY, VAUGHN C. MALEY, and HELEN PIER BIRD have changed their address from the Humble Oil and Refining Company at McCamey, to the same company at Midland, Texas.

H. M. FRITTS, formerly of Hammond, Louisiana, may now be addressed at the Shell Petroleum Corporation, Box 2099, Houston, Texas.

FREDERICK L. RANSOME, associated with the California Institute of Technology since 1927, died on October 6, 1935, at the age of 67 years.

JOHN W. CUSHING has changed his address from Bartlesville, Oklahoma, to the Petroleum Exploration Company, Box 413, Lexington, Kentucky.

P. E. FITZGERALD, with Dowell, Incorporated, is again located at Midland, Michigan, after spending several months in the Rocky Mountain area, including Colorado, Wyoming, Montana, and Alberta, Canada.

P. R. DEPUTY, formerly with The Texas Company, Los Angeles, California, is now doing consulting geology in Dallas, Texas. His address is 1035 North Edgefield Street.

T. F. NEWMAN, formerly Oklahoma district geologist for the Skelly Oil Company, has joined the geological forces of the Stanolind Oil and Gas Company in the Tulsa, Oklahoma, offices.

GILBERT W. NOBLE has changed his address from 36 Linnaean Street, Cambridge, Massachusetts, to 6917 Princeton Avenue, St. Louis, Missouri.

W. I. INGHAM, formerly of 402 Calhoun Street, Houston, is now with the Shell Petroleum Corporation as petroleum engineer in the East Texas Division, and is located at Kilgore, Texas.

E. R. BROCKWAY, formerly of Marshall, Illinois, may now be addressed at 1205 North Fifth Street, Durant, Oklahoma.

DAVID DONOGHUE, consulting geologist, Fort Worth National Bank Building, Fort Worth, Texas, has an article, "Explorations of Albert Pike in Texas," in the *Southwestern Historical Quarterly* for October, published by the Texas State Historical Association, at Austin.

CLARE COFFIN, of the geological department of the Stanolind Oil and Gas Company, presented a paper on "Peculiarities in Distribution of Oil and Gas

Fields in the Rocky Mountain Area," before the Tulsa Geological Society, November 4.

On November 3, the Tulsa Geological Society and the Mid-Continent Section of the American Institute of Mining Engineers visited the Tri-State Zinc district at the invitation of the Joplin-Miami Section of the A. I. M. E.

Lloyd A. Nelson, associate professor of geology at the Texas School of Mines, presented a paper on "Studies of the Carboniferous of the Franklin Mountains of Texas," before the Rocky Mountain Association of Petroleum Geologists at Denver, Colorado, November 4.

Minette Ries, on the geological staff of the Phillips Petroleum Company, has been transferred from Amarillo, Texas, to Oklahoma City, Oklahoma.

W. A. Thomas, chief divisional geologist in Michigan for the Pure Oil Company, has resigned effective November 1 to accept a position as chief geologist of the McClanahan Oil Company, independent Michigan company.

Ernest Obering is district geologist for the Shell Petroleum Corporation, at Midland, Texas.

L. W. Storm, formerly district geologist for the Sun Oil Company, Houston, resigned recently to join the Houston staff of the Schlumberger Well Surveying Corporation.

M. T. Halbouty, chief geologist and petroleum engineer for Glenn H. McCarthy Producing Company, Houston, was married October 19, to Miss Lesly Carlton, of Fort Worth.

William M. Barret, president of William M. Barret, Inc., has returned to Louisiana after spending part of September and October in California, where his organization is engaged in conducting an extensive geophysical survey.

Ray R. Moody, geologist with the Gypsy Oil Company, has changed his address from Tulsa, Oklahoma, to Box 304, Wakeeney, Kansas.

George R. Wesley has been transferred from Lexington to Owensboro, Kentucky, where he has charge of the Western Kentucky office of the State Department of Mines and Minerals.

V. E. Cottingham has been placed in charge of the petroleum engineering staff of the Texas Railroad Commission, with the title of director of oil and gas production and accounting.

Frederick W. Mueller, formerly with the Yount Lee Oil Company, Beaumont, is now with the Skelly Oil Company, 1305 Esperson Building, Houston, Texas.

Joseph M. Wilson, formerly with the Simms Oil Company, Dallas, is vice-president of the Texla Oil Corporation, 1802 Alamo National Building, San Antonio.

Carroll H. Wegemann accepted the position of regional geologist with the National Park Service, last May. His territory includes the Great Plains

and Rocky Mountains. His present address is 515 Custom House, Denver, Colorado.

LYNN K. LEE, geologist with the Pure Oil Company, has been transferred from Chicago, Illinois, to the Saginaw, Michigan, office, 402 Second National Bank Building.

WILLARD GILL has changed his address from Waco, Texas, to 166 Woodland, Worcester, Massachusetts.

PAUL M. BUTTERMORE has changed his address from Fort Worth, Texas, to Box 51, Mount Pleasant, Michigan.

JOHN C. POOLE, geologist with the Barnsdall Oil Company, formerly located at Houston, may now be addressed at Box 443, Victoria, Texas.

CHARLES GILL MORGAN, with the Seismograph Service Corporation, Tulsa, discussed the "Geology of the South Polar Region," at a meeting of the Tulsa Geological Society, Monday, October 21.

EUGENE WESLEY SHAW, of London, New York, and Washington, died at Washington, D.C., October 7, 1935.

RUSSELL FOSSLER RYAN, of Houston, Texas, died from injuries received in an automobile accident, October 8.

SAMUEL J. CAUDILL, of Tulsa, Oklahoma, died at Shelbyville, Kentucky, October 14.

CARLOS BURCKHARDT, geologist, of Mexico, died in October.

W. W. BOYER, consulting geologist, Casper, Wyoming, has an article on "Rocky Mountain Crude Oil Reserves," in the *Oil Weekly* of October 28 and November 4.